A Comparative Study of the Yellowtail Flounder from Three Atlantic Fishing Areas[1,2]

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ABSTRACT

Yellowtail flounders, *Limanda ferruginea*, from two Nova Scotian fishing areas, Middle Ground and Western Bank, and a southern region near Cape Cod were compared in 1946 with reference to rate of growth, sexual maturity, age and size composition, otolith growth, relative growth of three body parts, and meristic characters. The oldest and slowest-growing fish occurred on Middle Ground, the youngest and fastest-growing fish in the Cape Cod area. Cape Cod yellowtails matured sexually at a much younger age and smaller size than yellowtails from the other regions. Old large fish predominated in commercial catches from Middle Ground and Western Bank; commercial catches from the Cape Cod area were largely composed of young small fish. The 1943 year-class was dominant among the young age-groups on Western Bank; this year-class was scarce in the Cape Cod sample. The yellowtails of each area showed distinctive patterns of otolith growth. Otoliths of Cape Cod yellowtails differed from those of Middle Ground and Western Bank in the relative amount of growth in different years. Cape Cod fish had smaller heads and pectoral fins and larger otoliths than specimens from the other areas. Mean values of dorsal and anal fin-ray numbers were highest in Middle Ground and lowest in Cape Cod fish. Significant differences existed between the numbers of dorsal and anal fin-rays in Cape Cod yellowtails and each of the other samples; Middle Ground and Western Bank samples were not significantly different. Cape Cod yellowtails differed in all respects from either Middle Ground or Western Bank fish and it was concluded that in 1946 the Cape Cod yellowtails formed a distinct population.

Western Bank fish, although closely resembling those of Middle Ground, differed from them in some characteristics. It was suggested that the yellowtails of the two regions formed a large population possessing clines of characters.

Water temperatures appeared to be important in contributing to the differences between the populations.

INTRODUCTION

The commercial importance of the yellowtail flounder, *Limanda ferruginea* (Storer, 1839), has recently increased. This has been a result partly of the more frequent use of the otter trawler in North American Atlantic waters and partly of the large demand for fish during World War II. These factors led to a great development of the yellowtail fishery in New England waters where in 1942 more than 66,000,000 pounds of this species were landed. Although the annual yield is now much less, the New England fishery remains important. The annual Canadian catch is much smaller, about 2,500,000 pounds in 1946, but it is gradually increasing and should thus continue with the persistent change in the relative

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importance of the two principal methods of fishing for groundfish in Canadian east-coast waters. The most widespread method at present is line trawling which uses a hook too large to catch the small-mouthed yellowtail. Otter trawling, on the other hand, lacks this limitation and has produced large catches of yellowtails. The annual landing of this species at Canadian ports are shown in Table I.

TABLE I. Annual landings of yellowtails at Canadian ports, in hundreds of pounds, and their value in dollars.

Year	Cwt.	Value	Year	Cwt.	Value
1941	10,080	$14,800	1944	7,133	$14,266
1942	7,882	12,045	1945	19,191	38,382
1943	8,737	14,557	1946	25,592	51,184

The observations of Jordan and Evermann (1896–1900) and Bigelow and Welsh (1925) contain most of the recorded information on the yellowtail. These accounts, however, do not discuss in detail either the growth or the relationships of the yellowtails on different fishing grounds, subjects of prime importance to the proper understanding of a fishery. The present investigation was carried out during the summer of 1946 with the hope of increasing our knowledge of these important subjects. Fortunately, it was possible to examine specimens not only from two Nova Scotian fishing banks, Western Bank and Middle Ground, but also from an area near Cape Cod in New England waters. The purpose of this paper is to compare the characteristics of the yellowtails of the three areas in order to determine the degree of discreteness of the populations.

THE FISHING AREAS

The general range of the yellowtail, as reported by Bigelow and Welsh (1925), is "North American coastal waters, from the north shore of the Gulf of St. Lawrence, northern Newfoundland and the Newfoundland Banks to New Jersey". Detailed information on its distribution in Canadian waters is still lacking and probably will remain so until otter trawls are more widely used. The yellowtail is locally abundant in inshore Nova Scotian waters; it is, however, much more abundant in offshore regions. Landings as high as 50,000 pounds, about 30,000 fish, have been reported from Nova Scotian fishing grounds. Eastward, fishing skippers report that it is less common on St. Pierre Bank and uncommon on the Grand Banks.

The hydrography of the Nova Scotian banks has been described by Hachey (1942). According to Hachey, "the submarine physiography of the continental shelf to the southeast of Nova Scotia delineates an area that has been termed the Scotian shelf". The high areas of this shelf form the important Nova Scotian fishing banks (Figure 1). Middle Ground, one of the smallest of the principal banks, has depths ranging from 25 to 40 fathoms at its periphery to less than 20 fathoms at its centre. It is apparently separated on the south from Sable Island by a narrow stretch of deep water whose depths exceeds 90 fathoms. Western

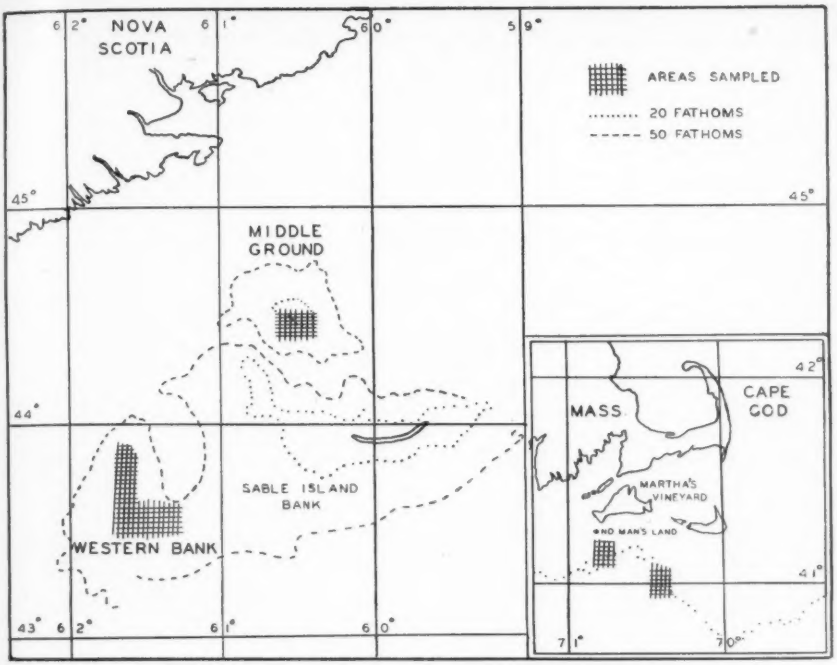


FIGURE. 1. Map showing localities mentioned in the text.

Bank is the part of Sable Island Bank lying west of 61°W. longitude and in general is less shallow than either Middle Ground or the eastern portion of Sable Island Bank. The western slope of Western Bank is not great and until 61°W. longitude is approached the depth is greater than 30 fathoms.

Hachey (1942) has outlined the general features of the waters of the Scotian Shelf. He stated that there were three layers of water whose thicknesses varied with the seasons: "an 'upper' layer with temperature in summer above and in winter below 5°C. and with salinities always less than 32‰; an 'intermediate' layer with temperature generally below 5°C. and with salinities between 32 and 33.5‰; and a 'bottom' layer with temperature above 5°C. and salinities above 33.5‰". The limits of these layers varied greatly with the seasons but, in general, bottom temperatures at 20 to 40 fathoms rarely exceeded 5°C. to any extent. Hachey recorded a bottom temperature of 6.4°C. at 35 m. on Middle Ground in August, 1938.

The fishing area herein referred to as the Cape Cod area lies south of Martha's Vineyard and its depths vary from 15 fathoms in the inshore region to more than 100 fathoms on the outer edge of the region. The locality considered in this account lies about 10 to 15 miles southeast of No Man's Land with water depths around 20 fathoms.

Olsen and Merriman (1946) included temperature records taken in the vicinity of Cape Cod. These temperatures at a depth of 20 to 25 fathoms varied from 2.4°C. in March to 14.3°C. in August, indicating that the maximum temperature was considerably higher than that encountered at similar depths on Western Bank or Middle Ground. This temperature difference was probably due in part to the effect of cold water moving from the northeast over the Scotian shelf (Hachey, 1938).

The factors governing the distribution of the yellowtail on the Nova Scotian fishing banks have not been carefully studied. However, the records of fishing vessels and my observations in these waters indicated that the species was most common in depths down to 30 fathoms. It became less common in deeper water and was rarely found in water deeper than 40 fathoms. This distribution placed it within waters belonging to Hachey's upper and intermediate temperature layers. Thus the yellowtail on the Nova Scotian banks apparently lives in waters with temperatures less than 5°C. in the winter while in the summer part of its habitat may be warmer than 5°C. Undoubtedly, the northern yellowtails live in colder waters than the Cape Cod fish.

METHODS AND MATERIALS

This paper is based upon data collected by the author from about 3,000 fish during the spring and summer of 1946. Most of the specimens were examined at sea; the remainder were taken from commercial catches landed at Halifax and Lunenburg, Nova Scotia, and New Bedford, Massachusetts. Unfortunately, seasonal variations in the commercial use of different fishing grounds made it impossible to obtain material continuously throughout the summer from Middle Ground and Western Bank. Specimens were collected from Middle Ground in May and June, from Cape Cod in July and from Western Bank in August and September. In addition, Dr. W. F. Royce of the U.S. Fish and Wildlife Service has most generously permitted the use of information on 908 yellowtails collected from the area between Nantucket Shoals and Montauk Point between July 1 and September 30, 1946. These data probably represent more accurately the yellowtail population of the Cape Cod area than do the author's data which were much more limited in scope.

The investigation of any population of fish should include an estimate of the age and size composition of the population. This can only be accurately achieved by good random sampling of the stock. In the present study, however, this was not possible for several reasons. Only large yellowtails, generally over 40 cm. in length, were landed at Canadian ports. Accordingly, nothing could be learned from commercial landings about the abundance of smaller fish. The work at sea was carried out on commercial trawlers in the course of normal fishing operations. This prevented accurate sampling, for many small fish were obscured or washed overboard during cleaning operations. Moreover, the large-meshed trawls used by the large Nova Scotian trawlers undoubtedly permitted the escape of many small flounders while retaining larger fish. Consequently, younger and smaller fish were not properly represented in the catches. Finally, the spawning season

apparently affected the distribution of the yellowtail on Middle Ground, for during the fishing in that area in May and June most yellowtails were large mature fish. However, subsequent fishing on Western Bank in August showed that the scarcity of small fish on Middle Ground in May and June was not entirely caused by the type of net used, for on Western Bank many small yellowtails were caught with similar gear. Although it is not possible with the present data to judge precisely the composition of the yellowtail stocks, sufficient specimens were obtained to permit a reasonable estimate of the growth of the species in the different areas.

The following information was recorded from all or some of the specimens.

SEX. The yellowtail is a thin flounder and this fact was invaluable in sex determination in the absence of external sexual differences. If a fish was held between the observer and a source of light (sunlight was sufficient), the lateral margins of the body were quite translucent. The ovaries, even in immature females, were clearly visible extending posteriorly from the body cavity between the ventral musculature and the interhaemal bones. In the males, on the other hand, the testes were always confined to the body cavity anterior to the large anal spine.

The sex was determined after all other measurements had been made. This prevented any personal bias concerning the measurement of parts in which sexual dimorphism might exist.

TOTAL LENGTH. This measurement, from the tip of the mandible to the distal end of the longest caudal fin-ray, was made to the nearest centimetre on a measuring board bearing at one end a shallow vertical board set half a centimetre to the left of the metre stick. Thus, when a fish was placed with its mandible resting lightly against the vertical endpiece, the first figure visible beyond the caudal fin represented the length to the nearest centimetre.

HEAD LENGTH. Head length was recorded to the nearest millimetre from the tip of the snout to the most posterior edge of the operculum.

RIGHT PECTORAL FIN LENGTH. This measurement was made to the nearest millimetre from the insertion of the fin to the tip of the longest fin-ray.

MERISTIC COUNTS. Dorsal and anal fin-rays were counted on approximately 200 fish from each area.

AGE. Otoliths were used for age determination. They were easily removed by making a deep transverse cut immediately behind the preopercular bone on the pigmented side. A 50 per cent solution of glycerin containing a few crystals of thymol was used as a preservative. Scales were removed from the pigmented right side of the caudal peduncle of some fish and were used to check the otolith readings.

Otolith reading was quite simple. Both otoliths are oval-shaped, convex on one side and flat or slightly concave on the other. The flat side of the left otolith was usually the easiest to read. Yellowtail otoliths are thin and the growth rings

were distinct without grinding or polishing. For examination, an otolith was placed in a drop of glycerin and examined under a binocular microscope (10.25 ×) using reflected light against a dark background. Each otolith of a pair was read without reference to the length or sex of the fish. If there was disagreement between the two readings, a third reading was made and a probable age given to the specimen. Although older specimens were occasionally difficult to read, it is unlikely that the error of estimation exceeded one year.

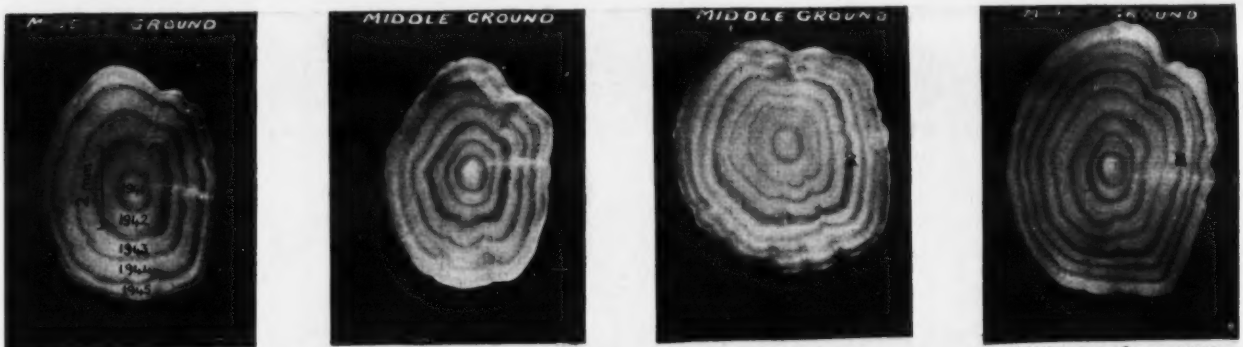
OTOLITH MEASUREMENTS. When the flat surface of the left otolith was first examined with the straighter edge facing away, it was noted that the left radius, measured along the long axis, was consistently greater than the right radius. Most of the difference was caused by a projection which always occurred on the left side of the otolith. This projection varied considerably in size, so it was considered that the right radius would portray more reliably the growth of the otolith. The right radius and the width of each pair of white and dark growth rings were measured in millimetres with an ocular micrometer.

OBSERVATIONS ON OTOLITHS AND SCALES

The features of otoliths are illustrated in Figure 2. There is a white opaque core occasionally bearing at its centre a small dark nucleus whose significance is not understood. Beyond the core is a dark translucent ring succeeded by a series of alternating white and dark rings. These rings become narrower and more difficult to distinguish as the edge of the otolith is approached.

The use of otoliths in the determination of age rests upon the assumption that a pair of adjacent white and dark rings represents a year's growth. Ideally, verification of this assumption would require either the rearing of fish to known ages with sampling of otoliths at different ages, or the collection of fish, ranging in sizes from newly hatched to mature fish, over a period of years and an analysis of changes in the appearance of otoliths in fish of various sizes. Such courses of action were impossible in the limited circumstances of this investigation and, consequently, only circumstantial evidence is available to support our original premise. For this purpose, it must be established (1) that the formation of the rings on the otolith is periodic, and (2) that the periodicity of otolith growth conforms to the pattern of annual growth of the fish.

Periodicity in the formation of the rings of an otolith can be readily demonstrated. The white and dark rings were apparently formed at different times of the year. In otoliths taken in May and June from fish on Middle Ground the outer edge was either dark or white (Figures 2A and 2B). In young specimens from Western Bank in late August (Figure 2F) the outer edge was usually a broad white ring, suggesting therefore that the white rings had been deposited during the late spring and summer, presumably under conditions favouring rapid growth of the fish. The dark rings would then represent growth during the fall or winter months. If these assumptions are correct, then each pair of white and dark rings was a year's growth. W. R. Martin and R. I. Peterson of the Atlantic Biological Station reached similar conclusions in 1946 regarding the growth of otoliths of the winter flounder, *Pseudopleuronectes americanus* (Walbaum).



A V, 30CM♀ 4 JUNE
B VI, 31CM♂ 3 JUNE
C VII, 38CM♂ 3 JUNE
D VIII, 40CM♀ 22 MAY
E IX, 42CM♀ 22 MAY
F III, 23CM♀ 23 AUG
G V, 32CM♂ 1 SEPT
H. VI, 38CM♀ 29 AUG

FIGURE 2. Otoliths from yellowtails of different ages from Middle Ground and Western Bank. Note the ring (X) and its position throughout otoliths A to E. Note the absence of this ring in F to H.

A peculiar growth pattern found only in the otoliths of some Middle Ground yellowtails also confirms the periodic formation of the growth rings. Figures 2A to 2E show otoliths taken from successively larger Middle Ground yellowtails. It will be noticed in Figure 2A that the second dark ring (X) from the centre is broad and distinct and probably reflects certain growth conditions at the time of its formation. A similar dark ring occurs successively one ring farther out in the succeeding four illustrations. The variation in the position of this ring in successively larger fish can best be explained in terms of age, the larger and presumably older fish having the marked ring nearer the edge than the younger and smaller fish. If this explanation is correct, then the position of the characteristic ring in relation to the core was a valuable indicator of age, particularly in cases where the peripheral rings were difficult to interpret. Its occurrence only in Middle Ground fish must be emphasized, for it indicates that at least some of the yellowtails on Middle Ground did not mix with the yellowtails on Western Bank.

The foregoing evidence indicates that the formation and occurrence of the rings on yellowtail otoliths were not haphazard and that the number of rings was directly related to the size of the fish and to the time of year when the fish was captured.

This evidence, nevertheless, does not show conclusively that a white and a dark ring form a year's growth. However, it is almost axiomatic that in northern waters fish do not grow at a constant rate throughout the year; rather, there is a period of rapid growth during the summer months followed by a period of slower growth. Probably, these two periods of growth are represented on otoliths by white and dark rings respectively and thus each pair of white and dark rings is a year's growth.

Further corroboration of the validity of the otolith method is afforded by the application of the length-frequency method of age determination (Lagler, 1952) to the length-frequency curves for Cape Cod yellowtails (Figure 4, below). One peak occurs at a length of 29 to 30 cm., a value which is very close to the mean length of fish whose otoliths showed two pairs of white and dark rings and which were thus judged to be two-year-old fish. The other and higher peak occurs at 35 cm. for males and 38 cm. for females, values which agree well with the mean lengths of fish with four or five pairs of white and dark rings. Conversely, the troughs or depressions in the curves are related to the scarcity of fish with otoliths bearing three pairs of white and dark rings. If our method of age estimation is correct, then in 1946 three-year-old fish were less abundant than those of adjacent age-groups. This is supported by Royce (personal communication) who, using scales for age determination, also concluded that three-year-old fish were scarce in 1946.

To sum up: although no direct evidence has been presented, circumstantial evidence suggests strongly that yellowtail otoliths provided a satisfactory method of age determination.

The age classification used is that adopted by most fisheries biologists. That is, a fish having completed its first year of life and beginning its second was one year old and was placed in age-group I. A fish in its third year of life belonged

to age-group II. Because of the variation in the outermost ring of different otoliths in May and June, some showing white edges and some dark, it was arbitrarily decided that all fish taken in these months had at least completed the formation of the dark ring of the preceding winter and were entering a new season of growth. Thus, all fish showing the same number of pairs of dark and white rings belonged to the same age-group and the same year-class. This decision avoided the inconvenience of placing fish of the same year-class into different age-groups.

European workers have rejected scales as unsuitable for the age determination of flounders. Nevertheless, Royce (personal communication, 1946) has successfully used scales in work on New England yellowtails. Accordingly, in this study scales and otoliths from the same fish were occasionally compared to determine their relative suitability in age determination.

This comparison favoured the use of otoliths for fish from Middle Ground and Western Bank. In young fish from these regions there was almost complete agreement between the number of rings on the otoliths and the number of annuli on the scales. However, in older fish from the Nova Scotian banks the outer areas of the scales were very difficult to interpret and beyond five years the accuracy of the reading was unsatisfactory. The interpretation of the outer rings on otoliths of old fish was sometimes difficult but even in fish over eight years old it was usually possible to determine the number of rings.

Otoliths and scales from Cape Cod fish were very different from those of their northern relatives. The otoliths were relatively larger with growth rings whose limits were frequently vague and diffuse, rarely showing the sharp contrast between dark and white rings so noticeable in the otoliths of Middle Ground yellowtails. The annuli on the scales were, on the other hand, quite distinct and easy to count. Scales were undoubtedly more suitable for the age determination of Cape Cod yellowtails but, as the bulk of the material consisted of northern fish, otoliths were used in the age determination of all fish.

The consistent differences in otoliths and scales of the three samples of yellowtails suggest that they were drawn from at least two separate groups of fish: one including Middle Ground and Western Bank yellowtails and the other, yellowtails from the Cape Cod region.

RATE OF GROWTH

It became apparent early in the investigation that there was a difference in the rate of growth between sexes; therefore the sexes were treated separately. The mean lengths of successive age-groups of fish from the three fishing areas are contained in Table II. Growth curves for male and female yellowtails from Western Bank and females from Middle Ground and Cape Cod are shown in Figure 3.

The growth curves were similar in form to those obtained for other species of fish (Tester, 1932; Hile, 1936). Growth in length was rapid in early life and gradually decreased in older fish. The rates of growth in male and female yellowtails from Western Bank were essentially the same between the second and

TABLE II. Mean lengths (l) in centimetres of successive age-groups from three regions and the numbers of individuals (n) examined. All samples are combined.

Age-group	Year-class	Middle Ground				Western Bank				Cape Cod				Cape Cod[a]			
		♂♂		♀♀		♂♂		♀♀		♂♂		♀♀		♂♂		♀♀	
		n	l	n	l	n	l	n	l	n	l	n	l	n	l	n	l
I	1945	..	..	..	..	..	..	1	9.2	..	..	..	..	..	..	1	17.5
II	1944	..	..	..	..	15	16.8	22	16.7	23	29.1	23	30.2	212	30.2	281	31.5
III	1943	1	22.0	3	21.0	56	21.5	65	21.3	14	34.0	20	35.0	35	33.8	38	35.2
IV	1942	11	22.3	7	23.7	23	26.6	14	26.0	23	34.4	18	37.3	73	34.9	109	37.7
V	1941	21	29.3	26	31.3	44	31.6	37	31.6	12	35.3	40	38.8	6	36.8	126	40.1
VI	1940	39	34.6	36	35.0	32	36.4	43	36.5	..	..	11	38.7	..	..	22	42.4
VII	1939	49	37.4	52	39.4	29	39.9	52	43.8	..	..	..	42.0	..	..	5	43.7
VIII	1938	68	40.1	44	42.8	28	41.3	60	46.0	..	..	..	..	..	..	..	..
IX	1937	36	42.3	50	45.3	16	42.0	51	46.2	..	..	..	..	..	..	..	..
X	1936	8	43.8	20	46.8	3	42.7	25	48.4	..	..	..	..	..	..	..	..
XI	1935	..	..	5	48.4	..	..	3	47.3	..	..	..	..	..	..	..	..

[a]These data were collected by Dr. W. F. Royce from the area between Nantucket Shoals and Montauk Point between July 1 and September 30, 1946. Scales were used by Royce in age determination.

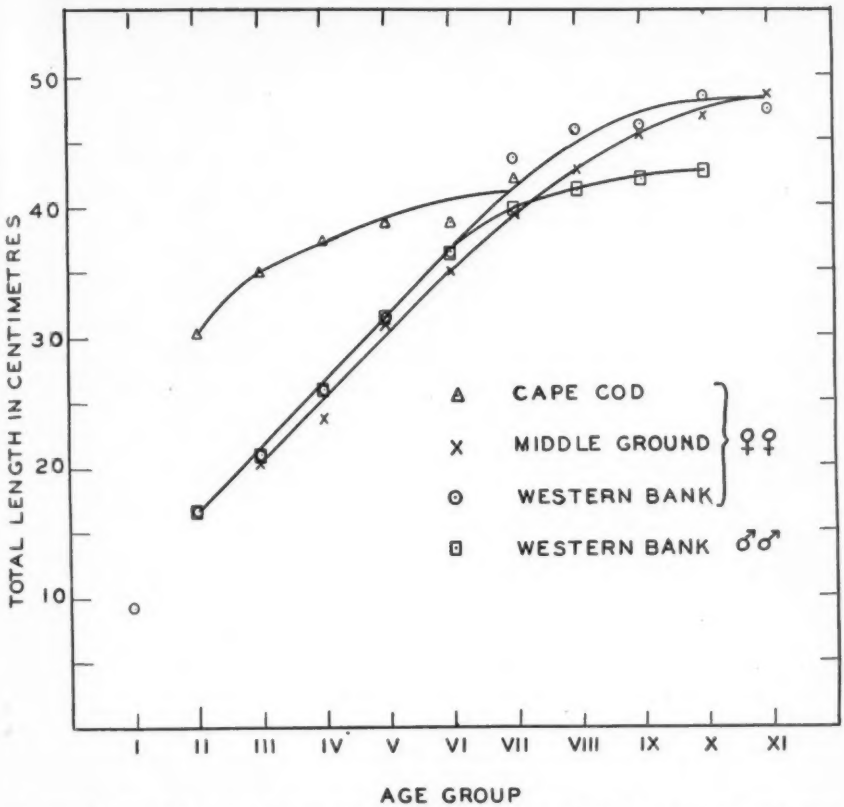


FIGURE 3. Rate of growth in length of female yellowtails from Middle Ground, Western Bank and Cape Cod. Males from Western Bank are also shown.

seventh years. Thereafter the growth curves of the sexes diverged; that of the males decreased sharply and remained low throughout the rest of life whereas that of the females continued at its previous rate until the eighth year when it also decreased sharply and subsequently remained low. Following the change in growth rates, the rates of both sexes were approximately the same. The data for Middle Ground fish were similar, namely, a marked diminution in the growth rate of males by the seventh year followed by a similar change for females about a year later. The relationship between the sexes from Cape Cod appeared like that of the other regions except that the distinct change in growth rates occurred much earlier, about the third or fourth year.

A comparison of the growth rates of females shows a striking difference between Cape Cod and northern yellowtails. Cape Cod females grew very rapidly during the first three years; age-group III fish had a mean length of 35 cm., a length not reached until the seventh year on either Middle Ground or Western

Bank. After the third year the growth rate of Cape Cod fish was considerably less than those of the other regions.

Western Bank females appeared larger than Middle Ground fish but some of this difference may have been due to different times of sampling. The mean lengths for Western Bank age-groups included the summer's growth of 1946, whereas Middle Ground fish, sampled in May and June, lacked the summer's increment. Although this may explain the differences in length between the younger age-groups of the two localities, it seems scarcely sufficient to account for the differences between older age-groups such as VII, VIII and IX. Possibly, therefore, Western Bank females were really, although only slightly, larger than those of comparable age-groups from Middle Ground.

The data on the males have not been illustrated; however, their growth patterns in the three regions bore essentially the same relationships to each other as did those of the females. The two groups of northern males had closely similar growth rates which exceeded that of the Cape Cod males after the first three years. Where all regions were represented within an age-group, the Cape Cod fish were by far the largest, with Western Bank males slightly larger than the Middle Ground specimens.

The general features of the growth of the Cape Cod yellowtails are confirmed by Royce's values, which show close agreement with the mean lengths of the younger age-groups in the writer's sample, although in the older groups Royce's values were consistently higher. Nevertheless, the divergence between the mean lengths of the older fish of the two samples is insufficient to invalidate the principal conclusions, namely, that the Cape Cod yellowtails had a much more rapid growth rate during the first three years than either of the northern groups and that the rate of growth of the Cape Cod fish after the third year was less than that of either group of Nova Scotian fish.

REPRODUCTION

SPAWNING PERIOD. Royce (personal communication, 1946) in 1943 found in the Cape Cod area that yellowtails began spawning by the middle of April and continued into the first week of July with maximum spawning in the third week of May. Observations in the present investigation in the same area indicated that spawning had ceased by mid-July.

Two hundred and two female yellowtails of commercial size from Middle Ground were classified according to their state of sexual maturity. The following classification was used:

IMMATURE—ovaries small; posterior prolongation less than 5 or 6 cm.
RIPENING—ovaries swollen but eggs not fully developed in size.
RIPE—some eggs ready for extrusion.
SPAWNING—eggs easily extruded by slight manual pressure.
SPENT—ovaries flaccid and apparently empty of eggs.

Table III shows the results of this examination. During the first fortnight of May the fish were still in a ripening condition and it was not until May 16 that appreciable numbers of ripe or spent fish were observed. By June 5 a definite

TABLE III. State of maturity of female yellowtails of commercial size from Middle Ground.

Date	Ripening	Ripe or spawning	Spent
May 1	11	0	0
May 3	14	0	0
May 6	21	1	0
May 9	30	0	0
May 13	22	0	1
May 16	22	5	5
May 22	14	11	3
June 5	5	28	9

change was apparent; the majority were in a ripe or spawning condition. This suggests that in 1946, on Middle Ground, maximum spawning took place in June, considerably later than the period of peak spawning noted for Cape Cod yellowtails.

All samples from Western Bank were taken in August and early September and at this time all large females, with one exception, were spent. Thus it was impossible to determine the spawning period on Western Bank.

AGE AND SIZE AT MATURITY. Only yellowtails from Middle Ground were examined during the spawning season when it was relatively simple to distinguish between immature and mature fish. Percentages of mature females examined from Middle Ground in May are shown in Table IV.

TABLE IV. The length and state of maturity of female yellowtails from Middle Ground in May.

Length (*cm.*)	34	35	36	37	38	39	40	41	42	43	44	45
% mature	0	0	17	17	9	31	50	80	86	95	97	100
Number	9	7	12	12	11	13	10	10	7	19	34	33

Sexual maturity in females was reached between 36 and 45 cm., a length range corresponding approximately to an age range of six to nine years. As the maximum life of Middle Ground females was about 11 years, the reproductive life of a female will rarely exceed five years. The growth rate of Western Bank females was sufficiently similar to that of Middle Ground females to indicate that the rate of reproductive development was probably also similar.

The females from the Cape Cod area matured at a much smaller size and younger age than the Middle Ground females. In the Cape Cod samples no females over 32 cm. long, with a single exception, were considered immature; this means that sexual maturity in these fish was reached at an age of three years or less.

Males from Middle Ground matured at a smaller size and younger age than the females. Most males between 30 and 35 cm. in length were mature. Although males from other regions were examined outside the spawning season, they also appeared to mature earlier than the females.

The information on the age and size of yellowtails at sexual maturity pro-

vides an explanation for the shape of the growth curves. It will be recalled that the growth rate of yellowtails from all areas decreased rather suddenly in later years. The onset of this decrease in each area coincided quite closely with the development of sexual maturity and probably was partly dependent upon it, for it is now generally accepted that sexual maturity inhibits somatic growth. Males apparently matured earlier than females, and in this connection it should be noted that the growth rate of the males decreased earlier than that of the females.

COMPOSITION OF COMMERCIAL LANDINGS

LENGTH-FREQUENCY COMPOSITION. As satisfactory length data from good random samples of entire populations were unobtainable, only the length-frequency compositions of commercial landings were compared (Figure 4).

Three major facts are evident from Figure 4. First, females greatly outnumbered males in the commercial landings from each area. Secondly, in each area, females grew to a greater length than the males. The modal lengths were 47, 44 and 38 cm. for females in contrast to modes of 42 to 44, 41 and 35 cm. for

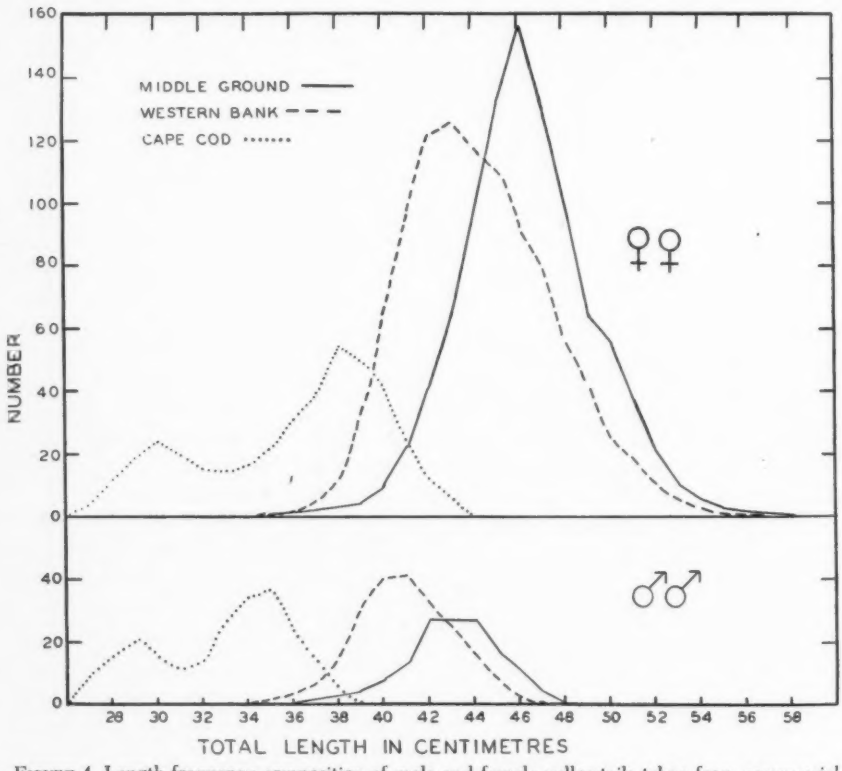


FIGURE 4. Length-frequency composition of male and female yellowtails taken from commercial catches from Middle Ground, Western Bank and Cape Cod. Data were smoothed by 3's.

males from Middle Ground, Western Bank, and Cape Cod, respectively. Thirdly, Middle Ground yellowtails grew slightly longer than those of Western Bank, which in turn grew much longer than Cape Cod yellowtails.

The bimodality of the curves for Cape Cod fish is interesting, since it was probably related to the relative scarcity of age-group III in the sample. That the scarcity of this age-group was not merely the result of sampling is borne out by Royce's more extensive data (Tables II and VI): these data show most strikingly that, in 1946, age-group III fish were much less common than those of adjacent age-groups. Apparently then, the weakness of this age-group was characteristic not only of the yellowtail population sampled by the writer but also of the yellowtails of a wider area south of Cape Cod.

AGE COMPOSITION. Table V shows the age composition of commercial landings from the three areas.

TABLE V. Age composition of landed catches (in per cent).

Age-group	Middle Ground		Western Bank		Cape Cod	
	117 ♂♂	144 ♀♀	69 ♂♂	190 ♀♀	72 ♂♂	129 ♀♀
II	..	..	..	..	31.9	21.7
III	..	..	..	..	19.4	16.3
IV	..	..	..	..	31.9	16.3
V	..	..	2.9	..	16.7	32.6
VI	8.5	5.6	13.0	5.3	..	8.5
VII	13.7	20.1	23.2	23.2	..	4.7
VIII	40.2	22.9	34.8	30.5	..	..
IX	30.8	34.0	21.7	26.8	..	..
X	6.8	13.9	4.3	12.6	..	..
XI	..	3.5	..	1.5	..	..

In all areas females tended to live to an older age than males. On Middle Ground, 51 per cent of the females were older than eight years against 38 per cent for males; on Western Bank, 41 per cent of the females were over eight years against 26 per cent for males; 46 per cent of Cape Cod females were older than four years against only 17 per cent for males.

These data and those of Royce clearly show that the youngest population occurred on Cape Cod where age-groups II, III, IV and V composed almost the entire sample. The northern samples, on the other hand, were largely composed of fish in age-groups VII, VIII and IX. The Middle Ground sample appeared to be slightly older than that of Western Bank.

To sum up, this analysis of commercial samples from the three regions with respect to length-frequency and age composition revealed distinct differences between the samples. The differences were most marked when the Cape Cod yellowtails were compared with yellowtails from either of the other areas. The Western Bank fish occupied an intermediate position, although resembling rather closely the Middle Ground sample.

RELATIVE ABUNDANCE OF YOUNG AGE-GROUPS. Different age-groups are often

not equally represented in a population of fish. This may be due in part to differential mortality affecting the year-classes as they become older and in part to fluctuations in the initial sizes of different year-classes with the result that certain year-classes may be more abundant than others. If the factors influencing the size of a year-class are localized in their effect, then other groups of the same species need not show a similar abundance or scarcity of the same year-class. The lack of similarity would then serve as a point of distinction between different populations. Table VI shows the relative abundance of four young age-groups from Western Bank and the Cape Cod region.

TABLE VI. Relative abundance, in percentage, of the year-classes of 1941 to 1944 of yellowtails, from Western Bank and Cape Cod. Numbers of specimens examined are in parentheses. Sexes are combined.

Year-class	1944	1943	1942	1941
Age-group	II	III	IV	V
Western Bank	13.4(37)	43.8(121)	13.4(37)	29.3(81)
Cape Cod	27.7(51)	19.0(35)	23.9(44)	29.3(54)
Cape Cod (from Royce)	56.0(493)	8.3(73)	20.7(182)	15.0(132)

The relative abundance of the four year-classes was not similar in the two fishing areas. On Western Bank the 1943 year-class was clearly the most abundant. The 1944 year-class, in spite of the much smaller size of the fish in it, was represented as frequently as the 1942 year-class. Apparently, then, the 1942 year-class was numerically weak in comparison with the other young year-classes. This aspect of age composition was not evident in the Cape Cod sample. In this area the 1943 year-class was weakly represented whereas that of 1942 was relatively stronger, a relationship sharply contrasting with the observations on Western Bank. This evidence indicates not only that the factors favouring the production of the rich 1943 year-class on Western Bank were inoperative in the Cape Cod area in 1943, but that the yellowtails of Western Bank and Cape Cod did not form a homogeneous stock.

ANNUAL INCREMENTS OF GROWTH OF OTOLITHS

If it is assumed that the widths of the rings of an otolith are indicative of the growth of the fish, then the annual increments to the otoliths and variations in the amount of these increments should reflect the past growth of any individual or any year-class. Moreover, because information on the early growth of a fish may be obtained in this manner, an analysis of otolith growth provides a more satisfactory method of comparing populations than examination of samples drawn largely from the old individuals composing the commercial landings.

The annual increments (t) of otolith growth of female yellowtails are shown in Table VII. Only the mean values for the males are given, as the detailed values for the males agreed closely with those of the females.

The three areas showed distinct differences in otolith growth. For the first three years, otoliths from Cape Cod yellowtails grew much more rapidly than

otoliths from northern fish. In Cape Cod fish maximum growth occurred in the second year. After the third year the annual increments decreased until they were consistently less than the increments of either Western Bank or Middle Ground otoliths. The first year's growth was approximately the same on both Middle Ground and Western Bank but t_2 and t_3 were distinctly greater on West-

TABLE VII. The annual increment (t) in millimetres of otolith growth in female yellowtails.

Year-class	Age-group	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
Middle Ground												
1943	III	.71	.71	.60								
1942	IV	.71	.50	.50	.50							
1941	V	.56	.67	.50	.46	.38						
1940	VI	.58	.51	.59	.43	.37	.37					
1939	VII	.48	.46	.49	.48	.34	.38	.34				
1938	VIII	.52	.49	.41	.42	.42	.31	.28	.27			
1937	IX	.55	.60	.50	.43	.30	.34	.23	.21	.19		
1936	X	.55	.56	.61	.44	.32	.25	.27	.19	.17	.20	
1935	XI	.49	.48	.61	.53	.22	.29	.24	.23	.12	.14	.12
Mean—♀♀		.54	.54	.51	.43	.35	.34	.31	.23	.18	.18	.12
♂♂		.55	.54	.45	.42	.32	.29	.26	.22	.16	.15	
Western Bank												
1945	I	.58										
1944	II	.67	.75									
1943	III	.50	.70	.63								
1942	IV	.59	.53	.57	.43							
1941	V	.54	.71	.48	.52	.31						
1940	VI	.61	.68	.60	.36	.38	.25					
1939	VII	.55	.67	.63	.47	.34	.33	.24				
1938	VIII	.58	.67	.59	.46	.33	.25	.23	.24			
1937	IX	.54	.67	.60	.42	.32	.30	.25	.20	.19		
1936	X	.60	.68	.64	.46	.31	.27	.22	.18	.16	.13	
1935	XI	.61	.65	.65	.45	.19	.20	.19	.19	.14	.13	.13
Mean—♀♀		.56	.68	.59	.45	.33	.28	.23	.21	.17	.13	.13
♂♂		.55	.69	.56	.45	.33	.23	.19	.19	.16		
Cape Cod												
1944	II	.67	1.56									
1943	III	.70	1.36	.79								
1942	IV	.69	1.34	.78	.40							
1941	V	.60	1.45	.82	.26	.28						
1940	VI	.58	1.55	.64	.38	.21	.19					
1939	VII	.64	1.51	.74	.33	.22	.17	.16				
Mean—♀♀		.65	1.46	.73	.37	.26	.19	.16				
♂♂		.63	1.45	.59	.32	.24						

ern Bank. Maximum growth of Western Bank otoliths clearly occurred in the second year, whereas on Middle Ground growth was almost equal in each of the first and second years. Following the fifth year the annual increments of Middle Ground otoliths exceeded those of Western Bank. Thus, Cape Cod and Middle Ground otoliths showed the two extremes of values; Western Bank occupied an intermediate position although its values more closely resembled those of Middle Ground.

There was considerable variation in the t_1 values from all regions. Some of this variation may have been due to selective sampling: for example, the fastest-growing fish in a year-class are apt to be caught first by commercial nets. It is not surprising, then, to note that increment values for the young age-groups usually exceeded the mean value for all age-groups. In certain cases, however, the variation cannot be so explained. For example, the t_1 value for the Western Bank 1943 year-class was 0.50, the lowest t_1 value recorded from this area, whereas the t_1 values for adjacent year-classes were much higher, 0.59 for the 1942 year-class and 0.67 for the 1944 year-class. At least part of this variation was probably due to differences in growing conditions during the first year of life of these year-classes. This belief is supported by the fact that these variations could be traced through the yearly increments of other year-classes. Low values for 1943 appeared in almost all young Western Bank year-classes. The low t_1 value for 1943 females was represented by low t_2, t_3 and t_4 values in the 1942, 1941 and 1940 year-classes, respectively. On the other hand, 1942 was apparently favourable for growth since a large annual increment was recorded as a t_1 value for the 1942 year-class and as t_2, t_3 and t_4 values for the year-classes of 1941, 1940 and 1939, respectively. The data for Middle Ground agreed closely with those for Western Bank, namely, large increments in 1942 and also in 1944, and low values in 1943. In these values, however, Cape Cod fish did not agree with the northern groups. Considering only the growth in 1942, 1943 and 1944, the greatest growth occurred in 1943, a situation opposite to that of Western Bank or Middle Ground.

An inverse relationship possibly existed between the amount of growth and the abundance of a year-class. On Western Bank the 1943 year-class appeared numerically strong, the 1942 year-class numerically weak. The amount of growth for the first year was much greater in the latter year-class. In the Cape Cod region, however, the relative strengths of these year-classes were reversed and the annual growth in 1943 was slightly greater than in 1942.

This analysis of otolith growth has shown not only that the yellowtails of each area possessed their own characteristic pattern of growth, but that the Middle Ground and Western Bank otoliths although agreeing closely with each other differed from those of Cape Cod in the relative amount of growth in specific years.

RELATIVE GROWTH

Different populations of fish may often be separated by differences in body proportions (Martin, 1949). However, body proportions do not necessarily remain constant, and frequently change with an increase in body size. This

change can best be illustrated and different samples most easily compared by plotting the logarithmic value of the body part against the logarithm of body length (Huxley, 1932). Head length, right pectoral fin length, and the radius of the left otolith of yellowtails from each area have been so considered. As the length range for adjacent age-groups overlapped considerably, the mean values of the body part in each age-group were plotted on logarithmic paper against the mean length for each age-group. Thus variation caused by any age-group will be apparent. The data for Cape Cod yellowtails were so limited in their length range that it was thought unwise to do more than plot the values for this area without attempting to joint the points. The results are presented in Table VIII and Figures 5 and 6.

For each body part the data for Middle Ground and Western Bank were so similar that a single line best fitted the data. There was no appreciable difference in the body proportions of yellowtails from these areas.

Slight differences existed between the proportions of Cape Cod fish and the northern samples. The radii of the otoliths were longer, particularly in older age-groups, while the heads and the pectoral fins were usually shorter than their northern counterparts.

It may be observed that, if the values for the otolith radius of Cape Cod yellowtails had been connected by a line, then the slope of this line would be different from that describing the relative growth of the otoliths from Nova Scotian fish. In view of the small sample and the closeness of the values to each other, much speculation about the reality of the difference in slope seems unjustified. However, it should be pointed out that a slight change in values for one or two ages, particularly at the extremities of the age range, might easily produce major changes in the slope of the relative-growth line. Moreover, Martin (1949) has shown that, although differences in body proportions may exist between populations of the same species or between closely related species, the slopes of the relative-growth lines for any particular body part are normally parallel. Probably, then, the apparent divergence in slope for the Cape Cod yellowtails from that of the Nova Scotian fish does not indicate a real intrinsic difference between the slopes of the relative-growth lines.

FIN-RAY COUNTS

Distinct populations of fish are frequently marked by numerical differences in their meristic characters (Rounsefell and Dahlgren, 1935). Probably the meristic characters best suited for examination in the field are fin-rays. Accordingly, counts of dorsal and anal fin-rays were made on samples from the three fishing areas. No significant difference between the sexes was noted, so the values for the sexes were combined (Table IX).

The distribution and means of the fin-ray numbers were analysed and compared by the method of analysis of variance described by Snedecor (1946). The tests were made to determine the validity of the hypothesis that the samples were drawn from one population. Tables X and XI contain summaries of the computations.

In the comparisons of dorsal and anal fin-ray numbers in Middle Ground

TABLE VIII. Head length, right pectoral fin length and otolith radius (all in millimetres) of successive age-groups from three areas. The sexes are combined.

Age-group	Head length	Number in sample	Mean total length of sample	Pectoral fin length	Number in sample	Mean total length of sample	Otolith radius	Number in sample	Mean total length of sample
Middle Ground									
III	43.5	4	21.3	19.0	4	21.3	2.00	4	21.3
IV	46.9	17	22.8	20.9	17	22.8	2.18	17	22.8
V	61.6	40	30.8	28.8	40	30.8	2.53	39	30.2
VI	69.7	66	34.7	32.3	66	34.7	2.73	59	34.0
VII	77.4	80	38.6	36.6	80	38.6	2.93	78	37.5
VIII	79.8	77	40.5	38.3	77	40.5	3.01	79	40.2
IX	86.7	56	43.7	40.1	56	43.7	3.26	60	44.2
X	93.9	17	46.4	42.7	17	46.4	3.45	23	45.6
XI	93.5	2	47.5	42.5	2	47.5	3.47	4	49.0
Western Bank									
II	34.9	28	17.0	15.4	28	17.0	1.79	31	16.9
III	43.8	83	21.7	19.9	83	21.7	2.03	97	21.4
IV	53.7	29	26.4	25.4	29	26.4	2.35	31	26.2
V	64.2	70	31.7	30.5	70	31.7	2.67	65	31.4
VI	73.4	70	36.5	34.2	70	36.5	2.94	47	36.1
VII	83.4	58	41.4	38.2	58	41.4	3.15	48	41.8
VIII	87.2	53	43.3	40.7	53	43.3	3.29	57	45.1
IX	90.7	39	44.7	41.7	39	44.7	3.43	45	46.0
X	94.4	15	47.1	42.4	15	47.1	3.63	19	48.3
XI	..	..	..	..	..	..	3.63	3	47.3
Cape Cod									
II	56.8	51	30.3	27.0	51	30.3	2.53	46	29.7
III	66.4	35	34.2	31.3	35	34.2	2.96	33	34.6
IV	69.1	44	35.6	32.5	44	35.6	3.17	39	35.6
V	75.3	54	38.0	34.4	54	38.0	3.38	52	38.0
VI	78.7	10	38.9	35.5	11	38.7	3.55	11	38.7
VII	85.6	5	41.4	35.8	6	41.8	3.76	5	42.0

and Western Bank yellowtails the F value in each case greatly exceeded the 5 per cent level of probability. Therefore the data did not disprove the hypothesis that the two samples came from populations with the same distribution of fin-ray numbers.

When each northern sample was compared with the Cape Cod fish, the F

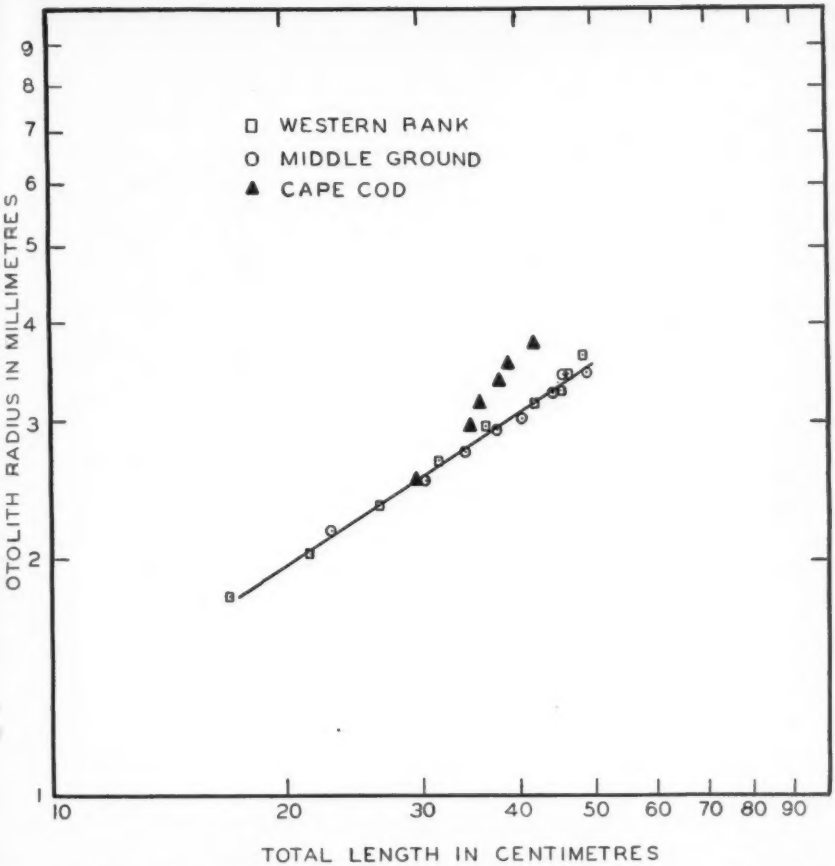


FIGURE 5. Relative growth of the left otolith in yellowtails from Middle Ground, Western Bank and Cape Cod. The sexes are combined.

value in each of the four comparisons was much less than the 1 per cent level of probability and the hypothesis must be rejected. With respect to anal and dorsal fin-ray numbers the Cape Cod yellowtails were distinct from either the Middle Ground or Western Bank yellowtails.

DISCUSSION

The causes of variation in the rate of growth and other characteristics of local populations of fishes are not completely understood, since it is difficult to separate the effects of genetic and environmental factors. Population densities, predation, interspecific competition and physical factors such as water temperature undoubtedly contribute greatly to differences between local populations.

TABLE IX. Frequencies (*f*) of dorsal and anal fin-ray numbers in the yellowtails from three areas. Sexes and age-groups are combined.

Number of dorsal rays	Middle Ground *f*	Western Bank *f*	Cape Cod *f*	Number of anal rays	Middle Ground *f*	Western Bank *f*	Cape Cod *f*
73	..	..	1	55	..	..	3
74	..	..	6	56	..	..	7
75	..	..	5	57	3	1	7
76	1	1	20	58	2	8	26
77	5	9	18	59	18	21	47
78	9	16	18	60	35	29	34
79	24	20	32	61	54	26	37
80	34	19	22	62	52	48	26
81	34	44	30	63	30	31	9
82	35	22	26	64	11	21	8
83	35	28	16	65	10	1	4
84	28	22	7	66	5	..	1
85	14	23	5	67	2	2	..
86	12	9	..	68	1	..	..
87	10	6	1	..	..	..	..
88	2	1	..	..	..	..	..
89	1	..	..	..	..	..	..
90	1	..	..	..	..	..	..
91	1	..	..	..	..	..	..
Totals	246	220	207	Totals	223	188	209
Means	82.11	81.80	79.61	Means	61.63	61.48	60.05

TABLE X. Summary of analysis of variance of dorsal fin-ray numbers.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Middle Ground and Western Bank					
Between samples	1	10.85	10.85	1.61	>5%
Within samples	464	3130.45	6.75		
Middle Ground and Cape Cod					
Between samples	1	698.16	698.16	99.0	<1%
Within samples	451	3178.34	7.05		
Western Bank and Cape Cod					
Between samples	1	509.86	509.86	72.9	<1%
Within samples	425	2970.29	6.99		

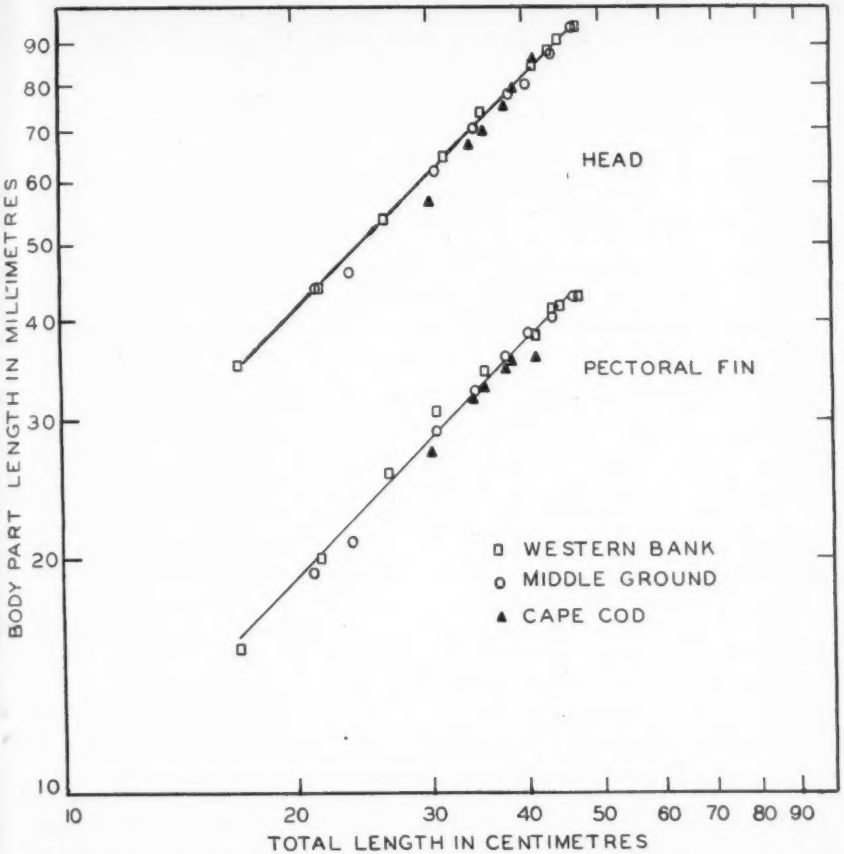


FIGURE 6. Relative growth of the head and the right pectoral fin in yellowtails from Middle Ground, Western Bank and Cape Cod. The sexes are combined.

Various effects of temperature are well recognized and have been discussed by many authors (Schmidt, 1919; Hubbs, 1926; Vladykov, 1934; Gunter, 1950). Acceleration of rates of growth, earlier sexual maturity, earlier onset of the spawning season, and decreased meristic numbers are commonly associated with high water temperatures. The ultimate age and size of fish have been shown to be inversely related to the early rate of development and, hence, indirectly to environmental temperatures.

The main differences between the Cape Cod and the northern yellowtails may be explained in terms of water temperatures. Water temperatures in the Cape Cod area have been shown to be considerably higher than those of the Nova Scotian banks and this difference in temperature is in accord with the observed differences in the samples. The Cape Cod stock, when compared with either of the two northern samples, showed a more rapid initial growth rate,

TABLE XI. Summary of analysis of variance of anal fin-ray numbers.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Middle Ground and Western Bank					
Between samples	1	2.27	2.27	0.68	>5%
Within samples	409	1369.02	3.35		
Middle Ground and Cape Cod					
Between samples	1	267.67	267.67	69.9	<1%
Within samples	430	1648.54	3.83		
Western Bank and Cape Cod					
Between samples	1	201.27	201.27	53.2	<1%
Within samples	395	1493.35	3.78		

earlier spawning season, sexual maturity at a smaller size and younger age, fewer dorsal and anal fin-rays, and a preponderance of relatively young, small fish.

Population density may also modify the characteristics of a group of fish and the possibility of its influence in the present case should not be disregarded. Peterson (1909) demonstrated that plaice transplanted from an area of high population density to a sparsely populated area showed a remarkable increase in their rate of growth. An increase in the rate of growth accompanying a decrease in the density of a stock of plaice was observed by Heincke and Bückmann (1926) according to Thursby-Pelham (1926). Although very little is known about the densities of the yellowtail on the Nova Scotian banks and the Cape Cod region, the large number of flounder draggers operating in New England inshore waters suggests that yellowtails are more heavily fished around Cape Cod than in Nova Scotian waters. If this assumption is correct, then the effects of different fishing pressures may be reflected, on the one hand, in the abundance of young age-groups in the Cape Cod fishery and, on the other, by the apparent accumulation of large, old yellowtails in the Nova Scotian stocks. Possibly, therefore, part of the variation between the samples, particularly that connected with size and age composition, was due to differences in fishing intensities and population densities in the various regions.

Throughout this paper the following assumption has been implied: if the yellowtails of the three areas belonged to a single, freely interbreeding population, then the characteristics of the three samples should have been very similar. If, on the other hand, the samples had different characteristics, then these would represent different genetic or environmental influences acting upon the species in different parts of its range and would indicate that the yellowtail did not form a freely interbreeding unit, but was composed of smaller reproductive groups at least partially isolated from each other. Similarity in characteristics, however, does not necessarily mean that the samples were taken from a single population for it is conceivable either that isolated stocks with little tendency to vary might remain closely similar or that larger samples might have revealed significant differences.

The yellowtails from Middle Ground and Western Bank were very similar, although there were slight differences in some features of the samples. These may have been due to the small size of the samples; nevertheless, it is noteworthy that, where differences occurred, the Western Bank yellowtails were always intermediate in their characteristics between the Middle Ground and Cape Cod specimens. This suggests that clines in characters, running approximately from north to south, may have been present throughout the range of the species. However, as long as nothing is known of the yellowtail in the areas separating the three localities studied, such a suggestion is largely hypothetical. The best evidence of a real difference between the Western Bank and Middle Ground yellowtails was a distinctive growth pattern (Figure 2) present in the otoliths of many Middle Ground fish. This pattern was not observed in Western Bank fish, and its absence indicates that the Middle Ground yellowtails were at least partially separated from those of Western Bank and that the stocks of the two regions did not freely interbreed. Possibly the Middle Ground and Western Bank fish may have been linked together by the yellowtails that undoubtedly occurred in the intervening region of Sable Island Bank to form a large group of yellowtails in which free interbreeding was prevented by the distance between the extremities of the range.

Appreciable differences, in all aspects examined, between Cape Cod yellowtails and samples of fish from Middle Ground and Western Bank were demonstrated. This indicates that there was little, if any, intermingling of Cape Cod and northern yellowtails, and therefore it is concluded that in 1946 yellowtails in the Cape Cod region formed a population distinct from the yellowtails of Western Bank or Middle Ground.

SUMMARY

1. Yellowtail flounders from two Nova Scotian fishing areas, Middle Ground and Western Bank, and a southern region near Cape Cod have been compared in an attempt to determine the discreteness of the yellowtails in the three areas.

2. The relative merits of otoliths and scales in age determination have been discussed. Otoliths were more suitable for yellowtails from the Nova Scotian regions, but scales were more satisfactory for the age determination of Cape Cod fish. Otoliths of yellowtails from Western Bank and Middle Ground had well defined growth rings in contrast to the diffuse vague limits of the annual rings of otoliths from Cape Cod specimens. Scales of Western Bank and Middle Ground fish were small and in old fish the outer areas of the scales were difficult to interpret. This difficulty was not encountered in Cape Cod scales because of the younger age of these fish.

3. The otoliths of some Middle Ground yellowtails were marked by a characteristic pattern not observed in otoliths from other areas.

4. The sexes grew at different rates. Initially the rates of growth in length were similar but, coincident with sexual maturity, the growth rates diverged. The growth rate for males decreased about a year before that of the females. Following sexual maturity, the rate of growth was low.

5. Maximum length and age were greater in the females.

6. The three samples showed consistent differences in rate of growth in length. The sequence with respect to early rate of growth, in order of decreasing magnitude, was Cape Cod, Western Bank and Middle Ground. The difference between Cape Cod yellowtails and those of either Western Bank or Middle Ground was much greater than the difference between the yellowtails of the Nova Scotian regions.

7. The spawning period on Middle Ground occurred appreciably later than in the Cape Cod region.

8. Cape Cod yellowtails matured sexually at a much younger age and smaller size than the northern yellowtails.

9. Male yellowtails from Middle Ground and probably those from the other regions matured earlier than the females.

10. Commercial catches of yellowtails from Middle Ground and Western Bank were composed of old, large fish. Middle Ground fish appeared to grow slightly older and larger than Western Bank yellowtails. Young, small fish made up the bulk of commercial catches from Cape Cod waters.

11. The 1943 year-class was abundant and the 1942 year-class was scarce in Western Bank samples. On the other hand, in Cape Cod samples the 1943 year-class was scarce whereas that of 1942 was slightly more common.

12. The annual growth of otoliths was studied. For the first three years, growth was greatest in otoliths from Cape Cod fish and least in those from Middle Ground. Thereafter the annual increments to the Cape Cod otoliths were less than the values for either Western Bank or Middle Ground fish.

13. Fluctuations in the amount of annual growth of otoliths of different year-classes were not consistent throughout the three areas. Cape Cod fish differed in this respect from the northern yellowtails.

14. Relative-growth studies of the head, the right pectoral fin and the left otolith revealed differences between Cape Cod yellowtails and yellowtails from the other areas. The head and pectoral fin were smaller, the otoliths larger, in Cape Cod fish. No appreciable differences between Middle Ground and Western Bank yellowtails were observed.

15. The mean values of dorsal and anal fin-ray numbers were highest in Middle Ground and lowest in Cape Cod fish.

16. Significant differences existed between the fin-ray numbers of Cape Cod yellowtails and those of either of the northern samples. There was no significant difference between Middle Ground and Western Bank yellowtails.

17. Temperature appeared to be an important factor controlling the observed differences in the samples.

18. Western Bank yellowtails were slightly different in some characters from Middle Ground yellowtails. It was suggested that yellowtails from these areas might be part of a large population, possessing clines of characters, in which complete intermingling did not occur because of the considerable distance between the extremities of the range.

19. It was concluded that the Cape Cod yellowtails in 1946 formed a distinct population isolated from the Western Bank and Middle Ground yellowtails.

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The General Oceanography of the Strait of Belle Isle[1]

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CONTENTS

Introduction	199
Background for investigation	199
The Belle Isle Strait Expedition of 1923	202
The Strait of Belle Isle	202
The tides in the Strait of Belle Isle	203
Hydrographic Features of the Strait of Belle Isle	204
Locations of stations	204
Vertical distribution of temperature, salinity and density in section	205
The horizontal distribution of temperature and salinity	215
Time series	216
T-S relationships	220
Current measurements	221
Drift-bottle results	223
The Esquiman Channel	229
Currents	229
Vertical distribution of temperature, salinity and density in section	230
The horizontal distribution of temperature and salinity	236
T-S relationships	236
Planktonic Invertebrates	239
The Fisheries and the Fish	245
Arctic immigrants	246
Southern immigrants	249
Endemic species	250
Summary	256
References	259

ABSTRACT

Hydrographic data for late August, 1923, show for the Strait (*a*) progressive inward movement on the north side of Arctic or sub-Arctic water, (*b*) progressive outward movement on the south side of Gulf water and (*c*) a dominant outward flow with evidence of a previous dominant inward flow. Time differences suggest tidal causes for the marked temperature and salinity changes. Current measurements for a double tidal period indicate residual trends of nine and eight miles per day in opposite directions on the north and south sides of the Strait. Inside, the Esquiman Channel shows two contra-clockwise eddies north and south of the Mekattina Bank. In addition, hydrographic data show a strong northeasterly movement along the Newfoundland shore and a weaker southwesterly one along the opposite Quebec shore.

Planktonic animals indicate the water movements, *Mertensia*, *Acartia spiniremis*, *Themisto*, *Pseudalibrotus* and *Oikopleura vanhöffeni* surviving to various degrees in the water from the Labrador Current that reaches the centre of the Gulf along the north shore of the Strait and Channel. Other forms characterize the warm shallow water along the Newfoundland shore inside the Strait and show its movement outward to the east coast of Newfoundland. The Greenland seal fishery of winter reflects the inward movement from the Labrador Current.

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Cod and herring fisheries invade this cool water of the north shore only locally in summer with access of warmer water from the south shore. Lobsters and cunners are very abundant in, but particularly confined to, the warm shallow water mentioned above.

INTRODUCTION

THE CIRCULATION of water in relation to the Strait of Belle Isle (Figure 1) at the northern entrance from the Atlantic to the Gulf of St. Lawrence, between Newfoundland and Labrador, is of great importance in understanding conditions in the Gulf that affect and determine the character of the plants and animals of the region. Passing southward along the outer coasts of Labrador and Newfoundland is the Labrador Current that brings cold water, floating ice and floating forms of life from the north. This current can affect conditions in the Gulf through the Strait of Belle Isle and also through Cabot Strait, the main entrance from the Atlantic to the Gulf, between Newfoundland and Nova Scotia.

BACKGROUND FOR INVESTIGATION

Circulation of water through the Strait of Belle Isle is very complex. A simple conception of it, which coupled it with the circulation through Cabot Strait, long prevailed. Bayfield (1837) wrote:

> It is a generally received opinion that a current sets constantly to the south-eastward out of the Gulf of St. Lawrence, between Newfoundland and Cape Breton Islands, and also that it is frequently deflected to the southward, towards the shores of the Island last named, by another current from the northward, which is said to enter the Gulf by the Strait of Belle Isle.

Nearly a century later, Dawson (1907 and 1920) wrote:

> the old idea so long prevalent, that the current in Belle Isle Strait is a constant one, flowing continuously towards the Gulf and passing around the west side of Newfoundland, to find its way out again, around Cape Ray, into the Atlantic

and

> the real difficulty in the case is to account for the persistence of the idea that this continuous flow exists . . . it may have originated from the casual observation of the drift of ice.

Dawson thus dismissed the facts responsible for the conception by considering the entrance of icebergs into the Gulf through the Strait of Belle Isle as "casual". He combatted the conception, not only as being misleading to navigators and thus perhaps responsible for shipwrecks, but also as giving false support to a project for damming the Strait (Dawson, 1920). He was at pains to replace the conception by another one, that circulation through the Strait is negligible.

> . . . it is clear now that no great inflow of water into the Gulf can take place through the Strait of Belle Isle [Dawson, 1896]. . . . the current under ordinary conditions turns regularly with the tide every six hours, in the usual way that tidal streams do. At times, there is a greater flow in one direction than the other; and it is possible for this flow to become continuous for two or three days together, with only a variation in speed which accords with the rise and fall of the tide. But this more continuous flow may be either inward towards the Gulf or outward towards the Atlantic; and observations throughout the season from June to September showed that on the whole it is nearly equal.

While such a statement of the case may be adequate for navigators, it fails

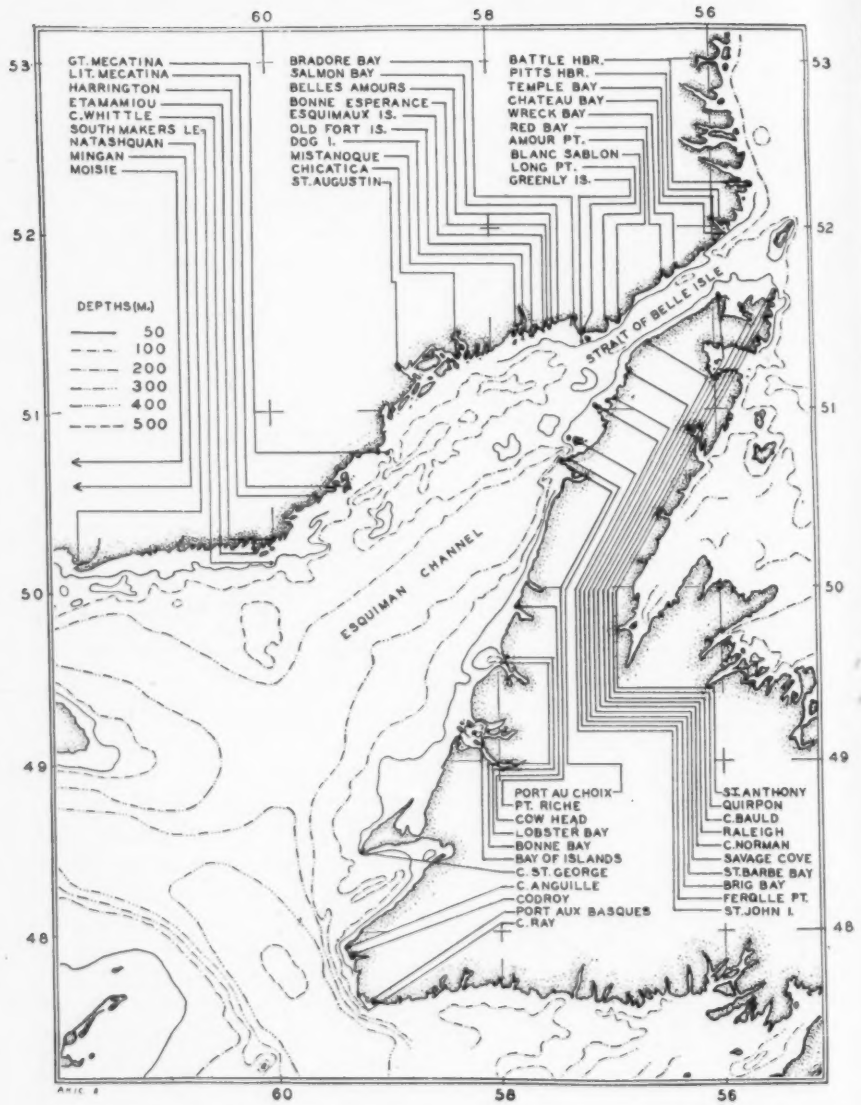

FIGURE 1. Chart of the region with depth contours and place names along the coasts of Newfoundland (*lower right*), Quebec (*upper left*) and Labrador (*upper right*), and with Cabot Strait and the Magdalen Islands near the lower left corner.

to take account of circulation that, although of negligible importance for navigation, is very potent in determining the character of the life inside the Gulf of St. Lawrence, including the fisheries there.

Although historically what is now the most populous part of Canada was discovered by Jacques Cartier in sailing inward through the Strait of Belle Isle and along the north shore of the Gulf, it is nevertheless a fact that population decreases steadily going in the opposite direction along this shore from Quebec to the Strait. What was first discovered supports fewest people. It would be foolish to attribute this wholly to circulation of water, but it would be equally foolish to deny the importance of a circulation which brings arctic conditions and forms of life so far southward. That it is related to water circulation is indicated by the fact that the arctic conditions on land are restricted to a narrow coastal zone.

Dawson (1895) compared the currents on the two sides of the Strait at its narrow part, near Amour Point, by measuring the current from a vessel anchored on one side and at the same time following the drift of icebergs on the other. He did, with the vessel on the south side, get a differential of more inward movement of the iceberg on the north side, but failed to get this when the vessel was on the north side and the icebergs on the south, with a persistent current from the east. He merely concluded that there was more persistent flow on the north because of the greater depth, and did not pursue the matter further. However, his observations of water temperatures for that season (1894) showed, in early August, water above 50°F. massed against the Newfoundland coast inside the Strait to a depth of 30 fathoms and extending through the Strait close to the south side in a mass more than 10 fathoms deep, not only as far as Cape Norman at the outer end of the Strait proper, but also as far as Cape Bauld on the open Atlantic. At this time, water from the Labrador Current, with a temperature less than 40°F. (4.4°C.) was along the north side unaltered at least as far inward as Wreck Bay opposite Cape Norman, but with a superficial covering of the warm water at Blanc Sablon, the inner end of the Strait proper. Only a differential in water movement between the two sides of the Strait serves to explain such a distribution of the warm and cold water. That the warm water was above the cold water at Blanc Sablon means that it was lighter. A double movement in opposite directions on the two sides of the Strait is necessary, if the condition observed at the outer end of the Strait is to continue for any length of time, namely that the water on the south side to a depth of 20 fathoms is lighter than even the surface water on the north side.

The matter of circulation of water from the Labrador Current into the Gulf of St. Lawrence through the Strait of Belle Isle arose in examination of material collected by the Canadian Fisheries Expedition of 1914–15. It was found that an Arctic Ctenophore, *Mertensia ovum*, was in the northeastern part of the Gulf of St. Lawrence as far west as Anticosti. No other explanation was to be seen than that it had been carried in through the Strait, and its distribution corresponded with what had been reported on occasion for icebergs that had clearly entered the Gulf through the Strait.

Study of Dawson's facts and of the forces involved led to the conclusion (Huntsman, 1923) that "this Strait exhibits a compressed cyclonic circulation

connected with the circulation of the Gulf of St. Lawrence at the one end and with the straight Labrador Current at the other". This was seen as resulting from the effect of the rotation of the earth on oscillations through the Strait, whether these were the short-term ebb and flow of the tide or the "dominant flows", sometimes westward and sometimes eastward, lasting for days, and probably due to wind or barometric pressure, that Dawson demonstrated. What seemed to be needed was a series of simultaneous measurements, on both sides of the Strait, that might demonstrate, not simultaneous movement of water in opposite directions on the two sides, but an overall differential from day to day in the set of the water on the two sides, which might, in the absence of any strong "dominant flow", result in water working inward along the north side as well as working outward along the south side. This could result according to theory (Thomson, 1880) from the action of the earth's rotation on the tidal oscillations through the Strait. It was calculated by Dr. Lachlan Gilchrist that such set of the water in and out might amount to as much as four miles per day. The Belle Isle Strait Expedition of 1923 had, as its main object, such simultaneous observations of the current on the two sides of the Strait, which required two vessels to be anchored one on each side during the same period. It was also hoped that observations would explain some rather striking hydrographic meteorological and biological conditions in relation to the Strait.

The Belle Isle Strait Expedition of 1923

The Expedition, under the direction of Dr. A. G. Huntsman, was sponsored jointly by the Biological Board of Canada, the Department of Marine and Fisheries, and the Newfoundland Government. The Department furnished the C.G.S. *Arleux*, and the Biological Board the Motorboat *E. E. Prince*. Dr. L. Gilchrist of the Department of Physics of the University of Toronto agreed to take part in the Expedition, and the Newfoundland Government took part in it by securing the services of Mr. Alan C. Gardiner of Cambridge University in England to assist in the work.

The Expedition started from Sydney, N.S., in July, 1923, and carried out hydrographic observations in Cabot Strait, the eastern portion of the Gulf of St. Lawrence, the Esquiman Channel, the Strait of Belle Isle, Labrador Current and the east coast of Newfoundland. In addition, plankton tows were made at numerous stations to supplement the hydrographic data, and a series of current measurements was carried out simultaneously on opposite sides of the Strait of Belle Isle for a period of several days.

The general results obtained were embodied in an article "The Ocean around Newfoundland", which was published in December, 1924, by the Newfoundland Government, and in January, 1925, by the *Canadian Fisherman*. The biological reports have, in part, been published by Davidson (1924), Pinhey (1927), Kerswill (1940) and Bousfield (1951).

The Strait of Belle Isle

The Strait of Belle Isle, lying in a NE.-SW. direction between the northern coast of Newfoundland and southern Labrador, joins the northeast portion of the Gulf of St. Lawrence to the Atlantic Ocean and is about 73 miles (118 km.) in

length from the south end of Belle Isle to abreast of Greenly Island near the Labrador coast. It has a width of 10 to 18 miles (29 km.) for 50 miles (80 km.) of its length, beyond which it widens rapidly in both directions. At its narrowest part, the depth of water does not exceed 35 fathoms (64 m.), while a maximum depth of 80 fathoms (146 m.) is found midway between Belle Isle and the Labrador coast. However, the average depth is approximately 40 fathoms (73 m.). The north shore is bold and the water off it is deep, whereas the south shore is low and sloping but the depths drop rapidly to 30 fathoms.

The Tides in the Strait of Belle Isle

From two extensive tidal surveys during the seasons of 1894 and 1906 in the Strait of Belle Isle, Dawson (1907) has carefully and clearly described the nature of the tides and tidal currents in the Strait. The general character of the current in Belle Isle Strait

> is primarily tidal . . . While under the control of the tide alone, it will turn regularly and run with equal strength in each direction; the flood setting westward and ebb eastward. But in addition to this tidal fluctuation, the water has almost always a tendency to make through the Strait in one direction more than in the other. While the tidal fluctuation goes on uninterruptedly, the water is thus making a continuous gain to the westward, or to the eastward, as the case may be. This over-balance in one direction we may term the element of dominant flow which is super-imposed upon the usual tidal fluctuation. It gives rise to much complication, as it is large in relation to the strength of the tidal streams, especially at the neaps when these are weak [Dawson, 1913].
>
> While the current is under the control of the tide alone, without any dominant flow in either direction to complicate matters, the usual astronomical conditions are to be distinguished. The effects which are chiefly noticeable in the tide and current in this Strait are:
>
> (1) the ordinary change from springs to neaps, with the moon's phases, and,
>
> (2) the diurnal inequality which is greatest when the moon is at its maximum declination north and south of the equator. This inequality is quite as distinct in the current as in the tide itself. At the maximum, its amount is so large that the difference in the strength of the current during the course of the day is distinctly greater than the difference between the springs and neaps. On the other hand, the variation in the moon's distance from perigee to apogee, has no appreciable influence in this region . . . [Dawson, 1907].
>
> The element of dominant flow . . . is the gain the water makes in one direction more than the other, notwithstanding the tidal fluctuation which checks it or helps it on. It is the over-balance of flow inwards or outwards through the Strait [Dawson, 1907].

The cause of this dominant flow has been attributed by Dr. Dawson to inequalities in the barometric pressures at the ends of the Strait of Belle Isle. He observed that in general, when the barometric pressure in the Gulf of St. Lawrence area was low, the dominant flow was westward, whereas when the barometric pressure was high the dominant flow was eastward. These conditions have been observed to last for a week or more, involving the whole body of water and not merely the surface layer.

At the eastern end of the Strait, the Labrador Current setting southward past the mouth of the Strait is influenced by the tidal inflow and outflow of the Strait itself. In general, the inflow is greatest on the north while the outflow is greatest on the south side of the Strait. The small amount of indraught towards the Strait in relation to the general drift of the Labrador Current is borne out by the drift

of icebergs. For every iceberg that enters the Strait from the vicinity of Belle Isle, five are carried southward along the coast of Newfoundland. It is only those that are close to the Labrador Coast that reach into the Strait.

The currents near the western end of the Strait have been described (Dawson, 1913) as variable and uncertain in their direction with frequent cross-currents. This area is enclosed by a line running from Rich Point to the Esquiman Islands and the narrowest part of the Strait at Point Amour.

HYDROGRAPHIC FEATURES OF THE STRAIT OF BELLE ISLE

In all, 139 hydrographic stations were occupied by the *Arleux* and the *Prince*. Of these, 109 were used in the preparation of this paper, in which the vertical distribution of temperature, salinity and density (σ_t) have been plotted, as have plans of temperature and salinity for depths of 0, 10, 25 and 50 metres.

Locations of Stations

The locations of the hydrographic stations used in this work are shown in Figure 2. In plotting the data in numbered sections, the sections are divided into

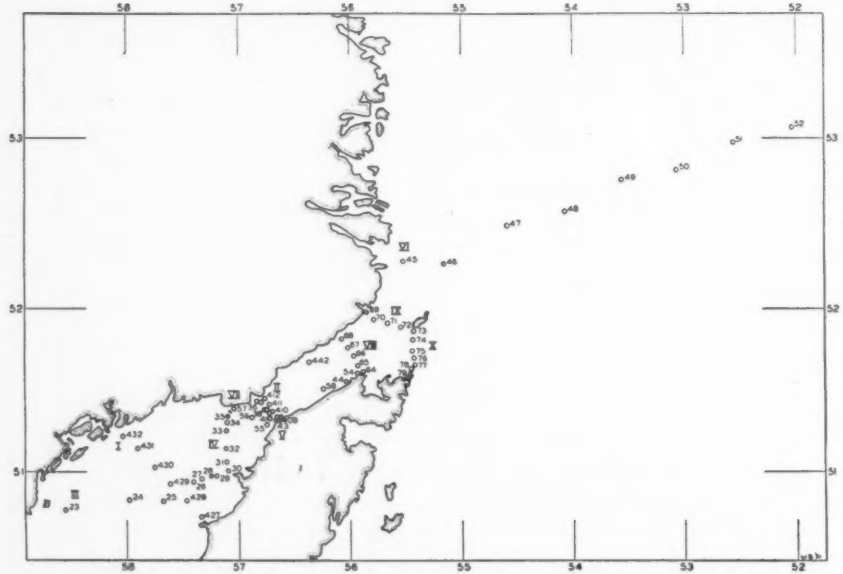

Figure 2. Locations of hydrographic stations. Belle Isle Strait Expedition of 1923.

three groups according to the times at which they were made, so that each group gives a maximum coverage in a minimum time with the available data.

Group A covers the period from July 30 to August 7 and includes the following sections:

Section I—stations 427–432, occupied on July 30 to August 2.

Section II—stations 408–412, occupied on August 7.

GROUP B covers the period August 15–21, and includes the following sections:

Section III—stations 23–30, occupied on August 15–16.
Section IV—stations 30–35, occupied on August 16–17.
Section V—stations 36–43, occupied on August 17.
Section VI—stations 45–52, occupied on August 18–19.
Section VII—stations 55–57, occupied on August 21.

GROUP C covers the period September 6–7 and includes the following sections:

Section VIII—stations 64–68, occupied September 6.
Section IX—stations 69–73, occupied on September 7.
Section X—stations 73–78, occupied on September 7.
Section II—stations 408–412, occupied on September 7.

VERTICAL DISTRIBUTION OF TEMPERATURE, SALINITY AND DENSITY IN SECTION

The vertical distributions of temperature, salinity and density in, and adjacent to, the Strait of Belle Isle are shown in Figures 3–19, inclusive.

In Figure 3, the vertical distribution of temperature (A), salinity (B) and density (C), within the period of July 30 to August 2, is illustrated for Section I, across the Western, or inner, end of the Strait.

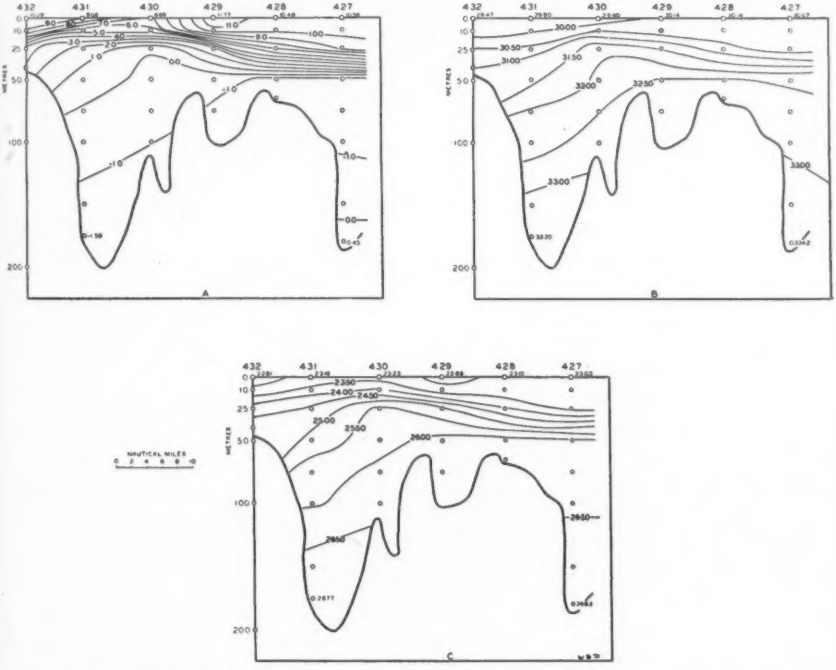

FIGURE 3. Distribution of temperature (A), salinity (B) and density (C) in Section I.

The main hydrographic feature of this section is the general stratification, in temperature and salinity, of the upper 40 metres. The main body of cold water has temperatures less than 0.0°C. and salinities greater than 32.0‰. In the upper 25 metres there are two bodies of warmer water, one on the northerly end of the section (stations 430–432) with salinities less than 30.0‰ and temperatures between 6.7° and 10.3°C., and the other on the southerly end of the section, less stratified, and with temperatures higher than 9.0°C. and salinities between 30.0 and 31.0‰.

Below 100 metres, salinities of more than 33.0‰ are associated with temperatures of less than −1.0°C. (as low as −1.58°C.) at station 431, whereas, at station 427, such salinities are associated with temperatures greater than −1.0°C. (as high as 0.45°C.). There is therefore a marked difference in the temperature-salinity characteristics of these waters. As will be noted in Section IV, to follow (Figure 5), the threshold depths prevent direct movement through the Strait at depths greater than 100 metres. It is quite probable, then, that the deeper waters as noted at station 427 are indicative of waters which enter the Gulf through Cabot Strait, and that the deeper waters observed at station 431 are related to an earlier influx through the Strait of Belle Isle. The slope of the isopycnals (C) indicates that there is a comparatively strong southwesterly movement in the water body beween stations 430 and 432, and a weaker northeasterly movement in the water body between stations 427 and 429. The southwesterly movement would seem to extend to considerable depth, whereas the northeasterly movement is confined chiefly to the upper 50 metres.

In Figure 4, the vertical distribution of temperature (A), salinity (B) and density (C), on August 7, are illustrated for Section II extending across the narrowest portion of the Strait. In the upper 25 metres, the north side of the

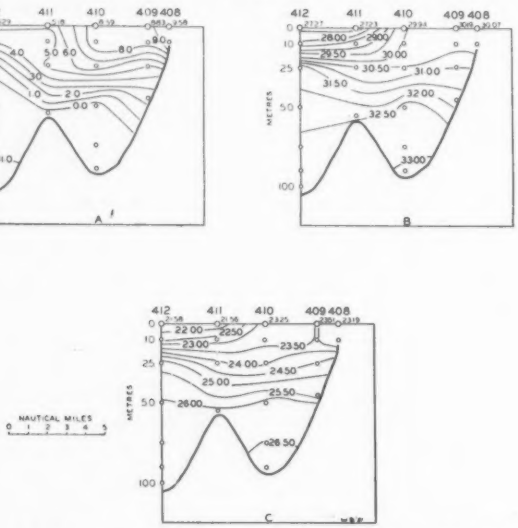

FIGURE 4. Distribution of temperature (A), salinity (B) and density (C) in Section II.

Strait, as represented by stations 411 and 412, has the colder (less than 6.0°C.), the less saline (as low as 27.27‰), and the lighter waters, and these waters are more highly stratified than those on the southern side. The waters on the south side of the Strait are well mixed to a depth of 15 metres, with temperatures greater than 8.0°C. and salinities between 30.0 and 30.5‰. Between 25 and 50 metres, comparatively high stratification is noted, whereas below the 50-metre level, water temperatures are generally less than 0.0°C., and salinities greater than 32.0‰.

The slopes of the isopycnals are indicative of water movements through the section, a westward component (i.e. inward) in the surface waters along the north shore of the Strait, and an eastward component in the surface waters between stations 408 and 409 on the south shore of the Strait. Below 25 metres, however, the slope of the isopycnals indicates that the movements at this depth are probably in the reverse direction.

The lower temperatures and salinities that are observed in the upper 25 metres on the northern side of the Strait are definitely associated with land drainage and are probably somewhat local in character.

The hydrographic conditions in the northeastern portion of the Gulf of St. Lawrence on August 14–17 are illustrated in Section III (Figure 5), which section runs almost due east and west between Newfoundland and Labrador. The surface temperatures, generally greater than 11.0°C. and associated with salinities less than 31.0‰, are relatively uniform across the section, except for stations 29 and 30. The strong thermocline existing between depths of 20 and 25 metres is a feature of the section. This thermocline comprises a temperature gradient of approximately ten degrees and a salinity gradient of more than 1.00‰.

The main body of water found below the 50-metre level in Section III consists of temperatures of less than 0.0°C., with corresponding salinities of greater than 32.5‰. It might be noted here that the high salinities of greater than 33.0‰, associated with temperatures as high as 0.45°C., which were found in Section I (Figure 3) close to the Newfoundland coast, are not in evidence in Section III.

The slopes of the isopycnals at depth give indications of strong southward movement of water between stations 23 and 24, and a slight northerly movement between stations 25 and 26.

Section IV (Figure 6) runs approximately in a north and south direction, and it is quite evident from the depths, which are less than 100 metres, that this section represents a threshold, which limits water movement through the Strait to the upper 100 metres.

In this section, surface temperatures are as high as 10.9°C. and marked stratification in temperature and salinity is evident at depths between 10 m. and 25 m. at stations 30, 31 and 32 on the Newfoundland side of the Strait, the vertical temperature gradient being as much as nine degrees, and the salinity gradient as much as 1.5‰. Between stations 33 and 35 a cold body of water of comparatively lower salinity is to be noted. Temperatures are from less than 0.0°C. to 3.3°C., and salinities of less than 31.5‰ extend to depths of 50 metres. Bottom tempera-

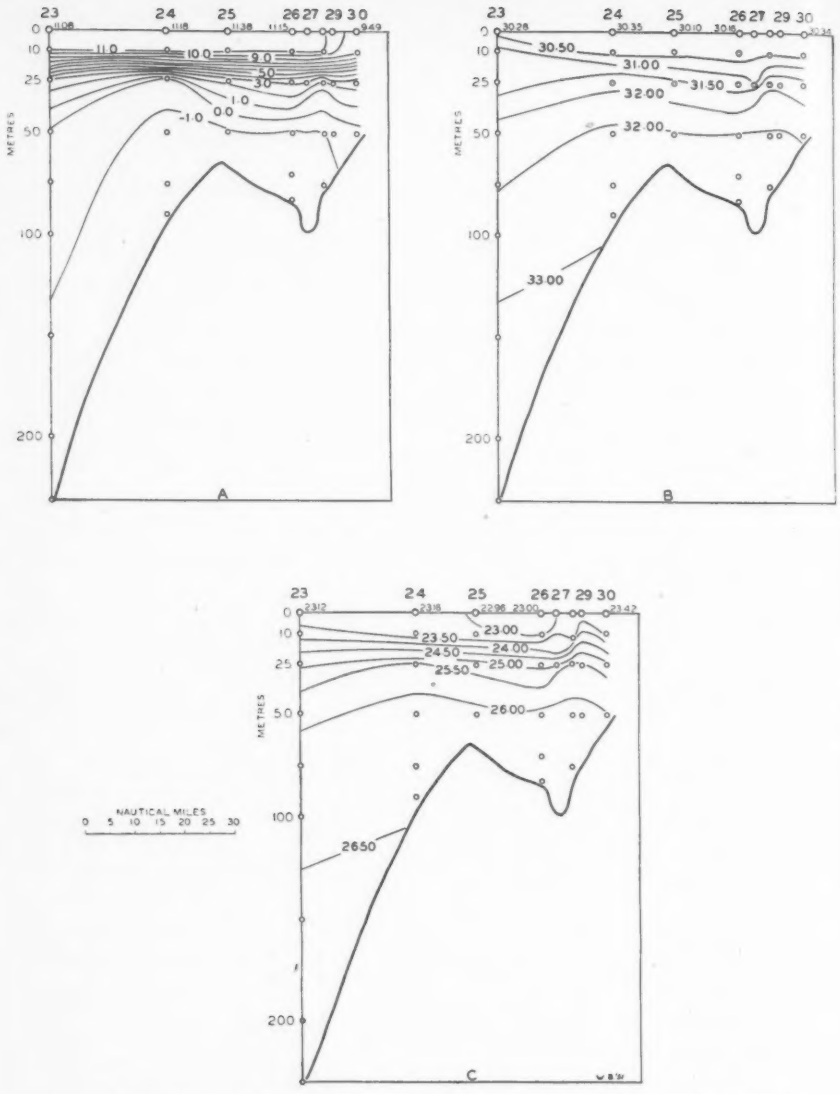

FIGURE 5. Distribution of temperature (A), salinity (B) and density (C) in Section III.

tures in the section are as low as —0.7°C., and salinities as high as 32.8‰. In this section the slopes of the isopycnals indicate strong easterly movement on the Newfoundland side of the Strait, and a westerly movement on the Labrador side.

The distribution of temperature (A), salinity (B) and density (C), on August 17 is illustrated for Section V in Figure 7. This section occupies the

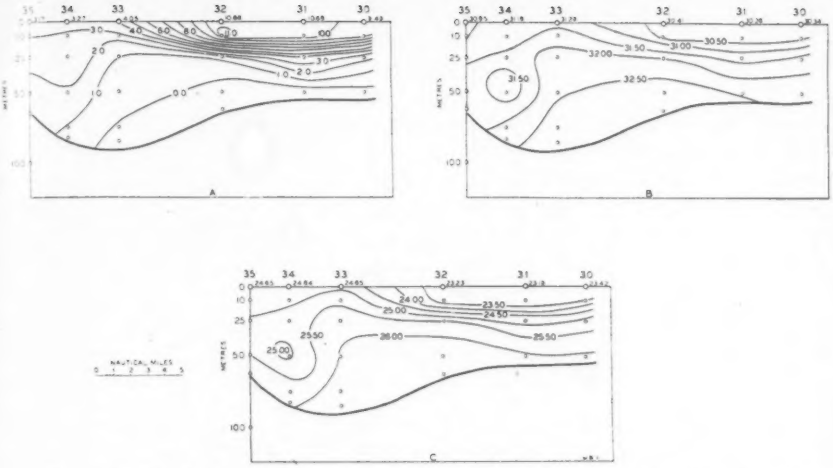

FIGURE 6. Distribution of temperature (A), salinity (B) and density (C) in Section IV.

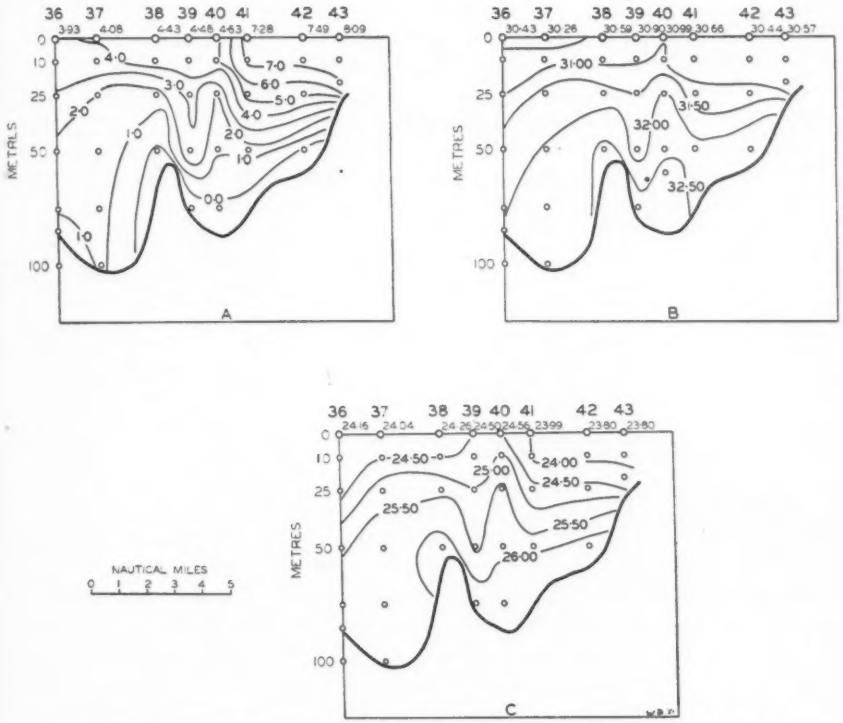

FIGURE 7. Distribution of temperature (A), salinity (B) and density (C) in Section V.

narrowest part of the Strait, and a threshold depth of 100 metres is in evidence on the northerly end of the section. The warmer body of water between stations 41 and 43, with temperatures as high as 8.1°C. on the surface and higher than 5.0°C. at 25 metres, is in contrast to the colder body of water between stations 36 and 39, which has surface temperatures no higher than 4.5°C. and temperatures as low as 2.0°C. at a depth of 25 metres. The horizontal temperature gradient between stations 40 and 41 (from 4.6° to 7.3°C.), which extends from the surface to at least 10 metres, outlines a demarcation between two bodies of water; this demarcation is also outlined by the isohalines and the isopycnals. The slopes of the isopycnals indicate a southwesterly movement along the Labrador coast (stations 36–38), and a northeasterly movement along the Newfoundland coast.

On August 18–19, Section VI was run at right angles to the Labrador Current, and the temperature (A), salinities (B) and densities (C), are plotted in Figure 8. Three distinct bodies of water are to be noted as follows:

(*a*) water of a temperature greater than 0.0°C. and a salinity less than 33.0‰, which extends to depths of 100 metres at station 45 and to depths of only 30 metres at station 52.

(*b*) water of a temperature less than 0.0°C. (as low as —1.6°C.) and a salinity between 33.0 and 34.0‰, which forms a layer of more than 200 metres thickness near the Labrador coast and which decreases to a thickness of 100 metres on the outer end of the section. This water, on the basis of temperature and salinity, is true Arctic water.

(*c*) water of a temperature greater than 0.0°C. and a salinity greater than 34.0‰, which is found at the greater depths offshore. This water is a mixture of the waters of the Baffin Land Current and the West Greenland Current, the latter being in greater proportion (Smith *et al.*, 1937).

The slope of the isopycnals indicates a strong southward movement close to the Labrador coast, where a band of light waters extend out to station 46. This band of water has been termed the inshore Labrador coast water (Bailey and Hachey, 1951).

Section VII, across the narrowest part of the Strait, was occupied on August 21. The distribution of temperature (A), salinity (B) and density (C), is illustrated in Figure 9. The slopes of the isotherms, isohalines and isopycnals indicate that the section was occupied when the dominant flow was outward from the Gulf. Sections II, V and VII, all located across the narrowest part of the Strait, were occupied on August 7, 17 and 21, respectively, and a comparison of the observed water characteristics and indicative flow is of interest. A cursory glance will show that the characteristic waters observed in Section VII on August 21 are similar to the warmer and less saline waters found in the upper layers of Sections II and V. The colder and more saline waters (temperatures as low as —1.0°C. and salinities as high as 33.0‰) are not in evidence. The comparatively steep slope of the isopycnals in Section VII, with the lighter waters piled on the Newfoundland coast, is in contrast to the density distributions in Section II and V. Temperatures throughout Section VII on August 21 are generally higher than 3.0°C. and as high as 11.0°C. Salinities are lower than 31.5‰.

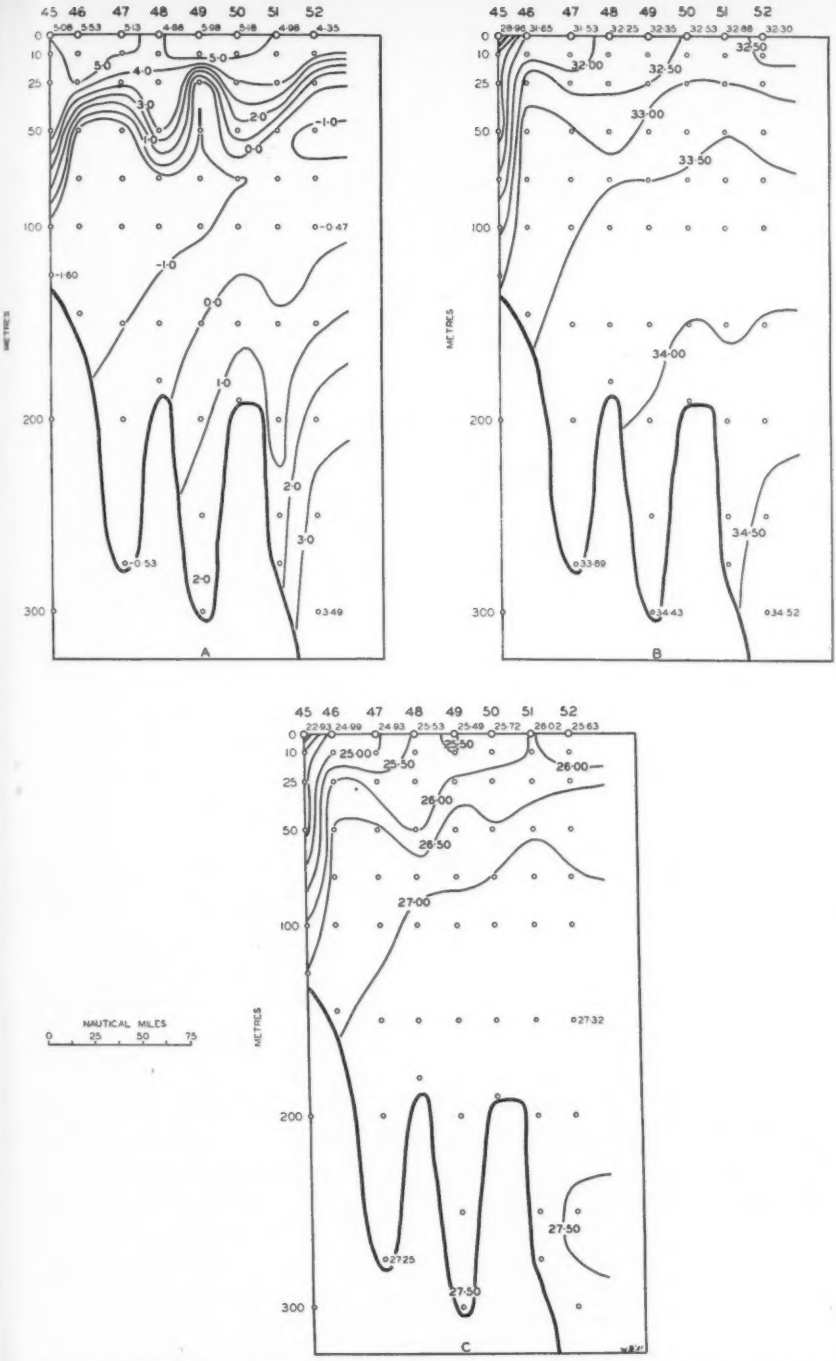

FIGURE 8. Distribution of temperature (A), salinity (B) and density (C) in Section VI.

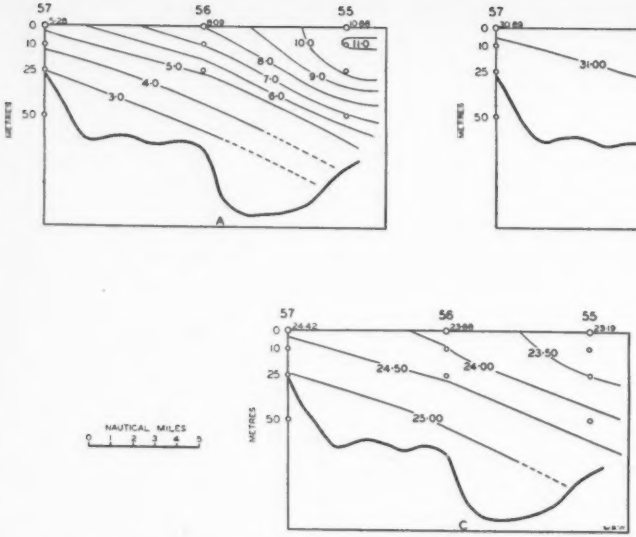

FIGURE 9. Distribution of temperature (A), salinity (B) and density (C) in Section VII.

Sections VIII, IX and X at the northeastern end of the Strait, and Section II at the narrowest part were occupied on September 6 and 7.

The distribution of temperature (A), salinity (B) and density (C) in Section VIII is illustrated in Figure 10. The slopes of the isotherms, isohalines and isopycnals indicate that the dominant flow is outward at this time, with the warmer, less saline and lighter waters occupying the southerly portion of the section. The temperature gradients on the bottom, from —1.0°C. in the middle of Section VIII at a depth of 100 metres, to 10.0°C. at a depth of 30 metres off the Newfoundland coast, with corresponding changes in salinity, are of considerable biological significance.

The waters carried to the area from the north between Belle Isle and the Labrador coast are illustrated in Section IX (Figure 11). On September 7 the temperature range was from 5.6°C. on the surface to less than —1.0°C. on the bottom, and the salinities ranged from 29.0‰ on the surface to greater than 33.0‰ at 100 metres.

In Section X (Figure 12), the characteristic waters between Belle Isle and Newfoundland are illustrated. The temperatures of the section on September 7 range from 9.3°C. on the surface to less than —1.0°C. at a depth of 100 metres, and the salinities range from 30.3‰ on the surface to greater than 35.5‰ at a depth of 100 metres. The distribution of density, as illustrated by the isopycnals, shows that the predominant movement was that of the warmer surface waters outward around the northern tip of Newfoundland.

Figure 13 shows that on September 7 in Section II, across the narrowest part of the Strait, there had been a considerable change in the waters since

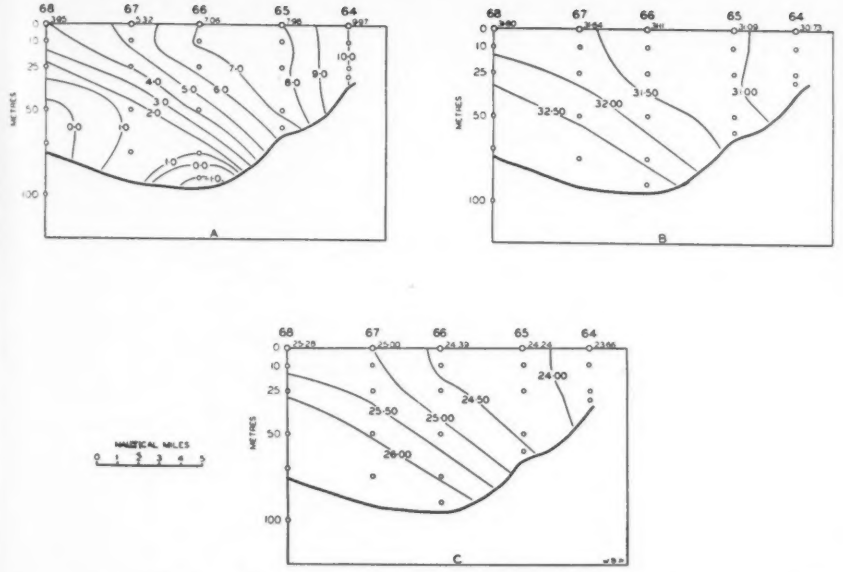

FIGURE 10. Distribution of temperature (A), salinity (B) and density (C) in Section VIII.

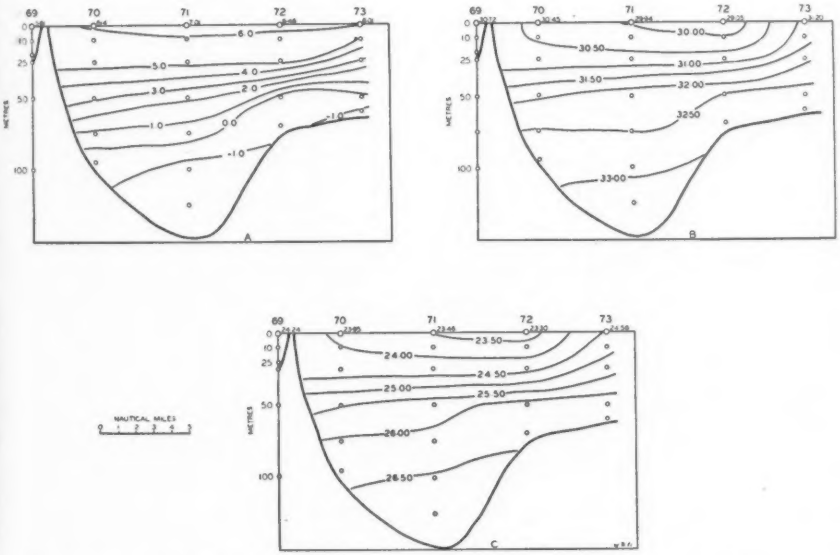

FIGURE 11. Distribution of temperature (A), salinity (B) and density (C) in Section IX.

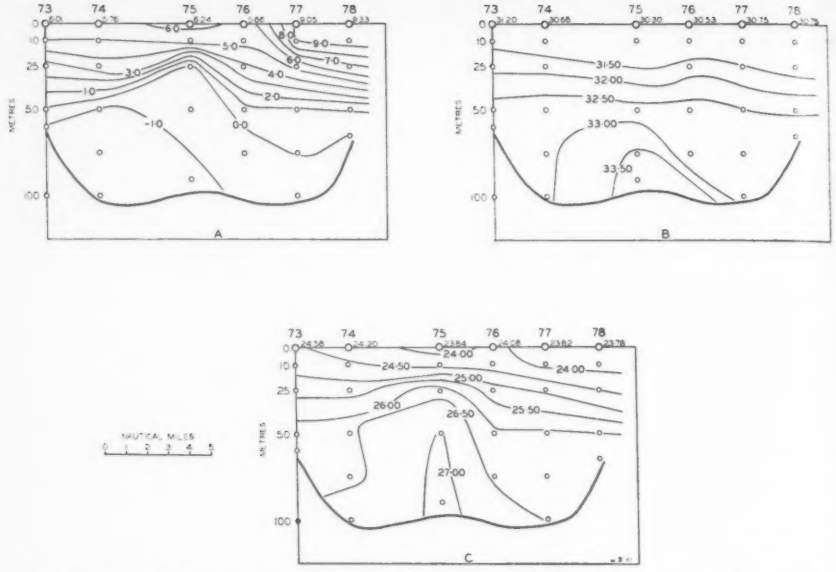

FIGURE 12. Distribution of temperature (A), salinity (B) and density (C) in Section X.

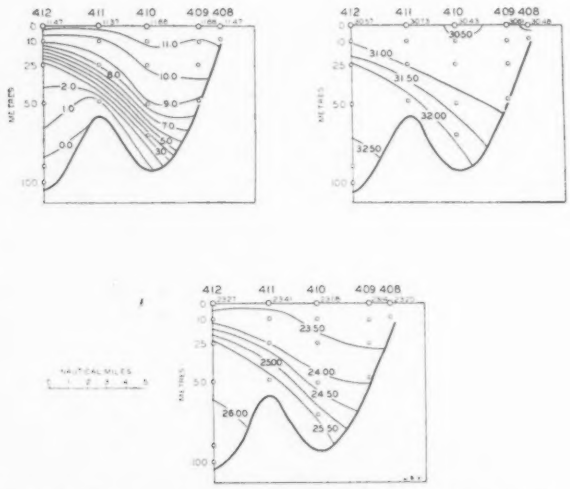

FIGURE 13. Distribution of temperature (A), salinity (B) and density (C) in Section II.

August 7 (Figure 4). The waters on this latter date are warmer, less saline and less dense at all levels, thus demonstrating a complete replacement of the waters in the Strait. The slopes of the isopycnals indicate that there is a predominant movement eastward through the Strait at this time.

THE HORIZONTAL DISTRIBUTION OF TEMPERATURE AND SALINITY

The horizontal distribution of temperature and salinity obtained from the observations spread over the period July 30 to August 7 is shown for depths 0, 10, 25 and 50 metres in Figure 14. The general tendency of the isotherms and

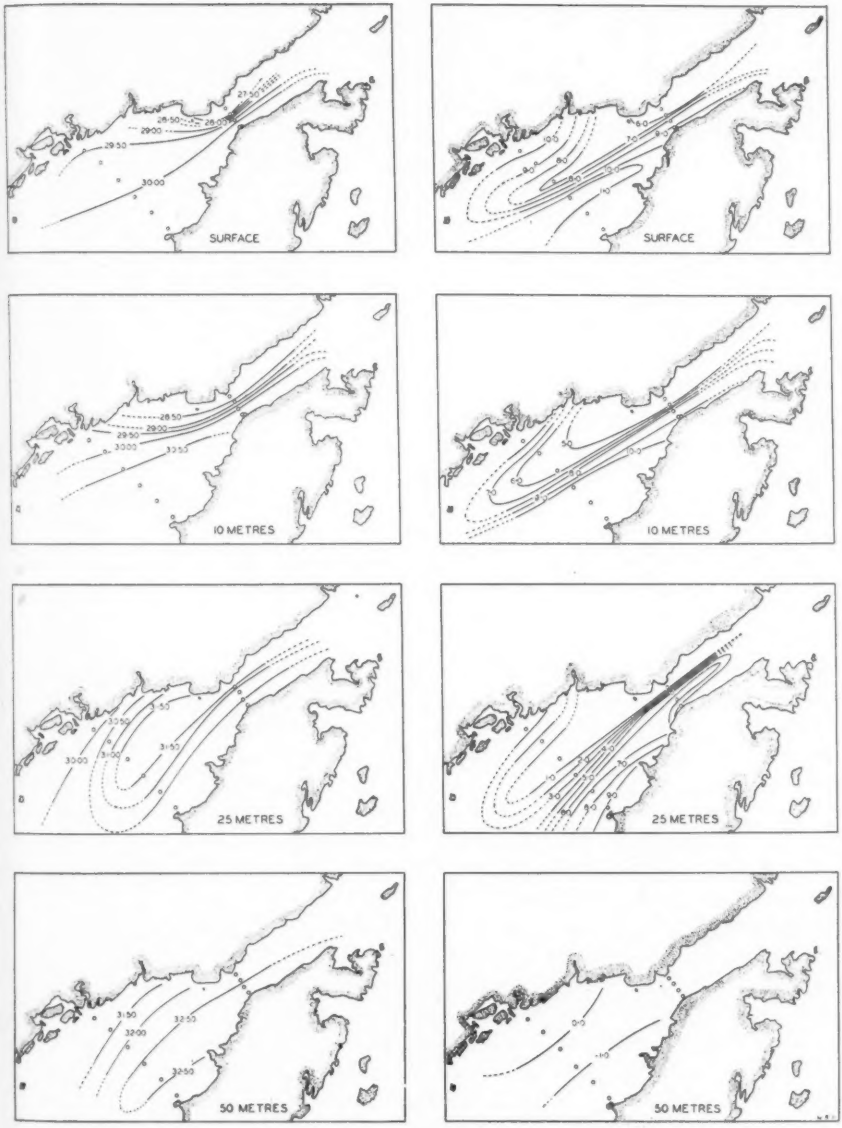

FIGURE 14. Distribution of temperature and salinity in Belle Isle Strait, July 30 to August 7, 1923.

isohalines toward a northeast-southwest direction is well illustrated at depths of 0, 10 and 25 metres, and we note that the colder and less saline waters hold to the Labrador side of the Strait. There are indications, therefore, of a double movement in the Strait to depths of at least 50 metres, with the Labrador coastal waters tending inward into the Gulf of St. Lawrence, and the Gulf waters tending outward along the Newfoundland side of the Strait.

The horizontal distribution of temperature and salinity obtained from the observations spread over the period August 15–21 (Figure 15) presents a rather confused picture. In the upper 10 metres, the colder waters of less than 7.0°C. would indicate that there are strong movements inward toward the Gulf during this period. Other than that, the composite picture does not allow a reliable interpretation.

The complete coverage of the narrower portion of the Strait by the observations of September 7 affords a more complete picture of the horizontal distribution of temperature and salinity. As has been mentioned in dealing with the sectional distribution of the waters on September 7, the observations indicated a prominent and dominant northeasterly flow, outward from the Gulf. This picture is considerably enhanced by the horizontal distribution of Figure 16. Waters of temperatures higher than 0.0°C. occupy the Strait, with warmer waters (as high as 11.0°C.) being quite prominent to depths of 50 metres. These higher temperatures, holding to the centre and Newfoundland side of the Strait, are associated with salinities of less than 32.0‰.

Both the isotherms and the isohalines run generally in a northeast-southwest direction. The flow of Labrador coastal waters of comparatively lower temperatures seems, from the trend of both isotherms and isohalines, to be diverted through the passage between Belle Isle and Newfoundland.

Time Series

On September 24, 1923, with the *Prince* anchored at station 442 and the *Arleux* anchored at station 58, hydrographic observations were commenced at 1700 hrs., both ships taking temperatures and water samples at several depths until 2000 hrs., September 27. Temperature and salinity data from these observations are plotted against time in Figures 17 and 18, respectively.

The temperature-time data show that there is a marked variation of temperature with time and that there is a considerable difference between the temperature structures of the water columns on the two sides of the Strait during this particular series of observations.

In particular, the waters on the south side (station 58) show a well-developed surface layer and a marked thermocline, which is typical of the waters of the Gulf of St. Lawrence at this time of year, whereas those on the north side show a fair degree of mixing to depths greater than 20 metres, which is similar to the thermal structure of the waters found north of Belle Isle (Bailey and Hachey, 1951). The maximum difference in temperatures at the surface and at 35 metres is approximately 4.0°C., station 58 having the highest and the lowest temperature in each case.

The salinity-time relationships (Figure 18) are markedly similar to the temperature-time relationships, but the variations are not as pronounced. Salinities at station 442 range from less than 30.3 to greater than 31.3‰, and at station 58 the surface salinities increase slightly from 30.5 to 30.7‰ during the time of

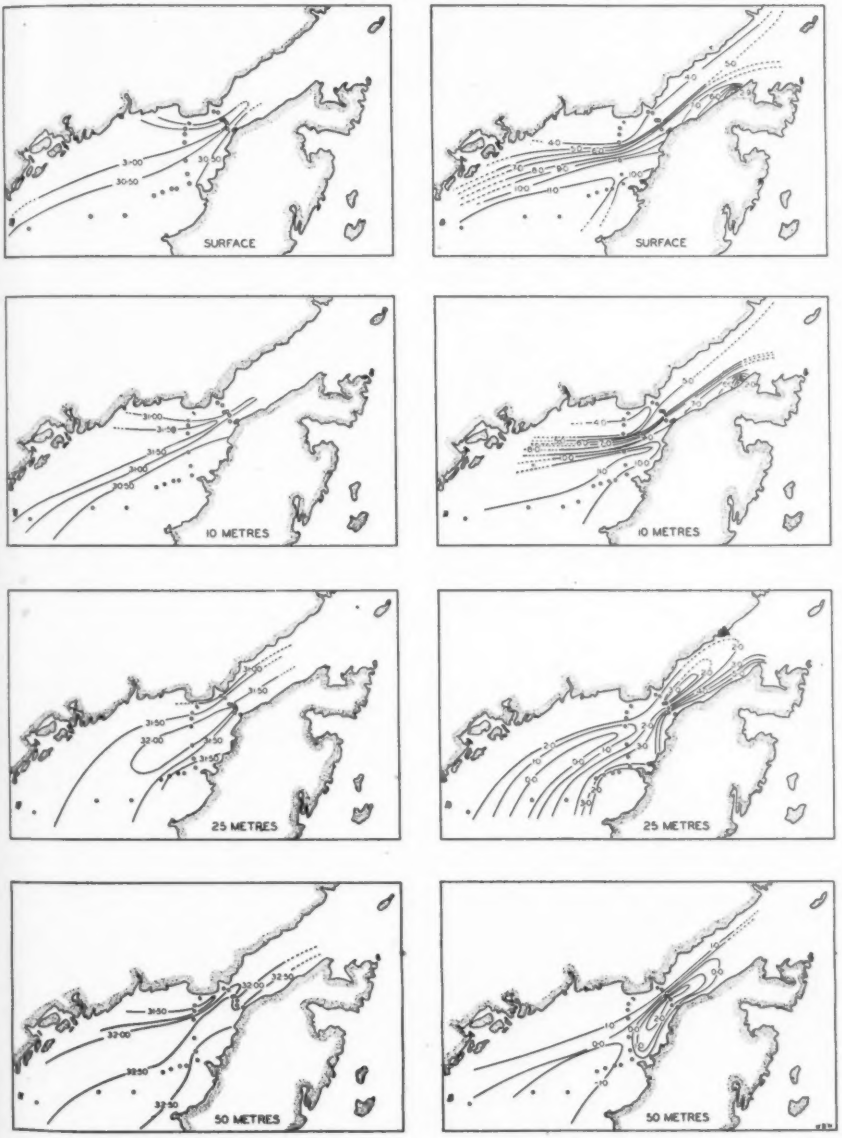

FIGURE 15. Distribution of temperature and salinity in Belle Isle Strait, August 15–21, 1923.

observation. Near the bottom there are greater fluctuations, and the salinities range from 31.0 to 32.0‰ at station 442, and from 30.6 to 33.0‰ at station 58.

It is obvious that the structure of the water columns undergoes considerable change with time; and the time difference between maximum temperatures and

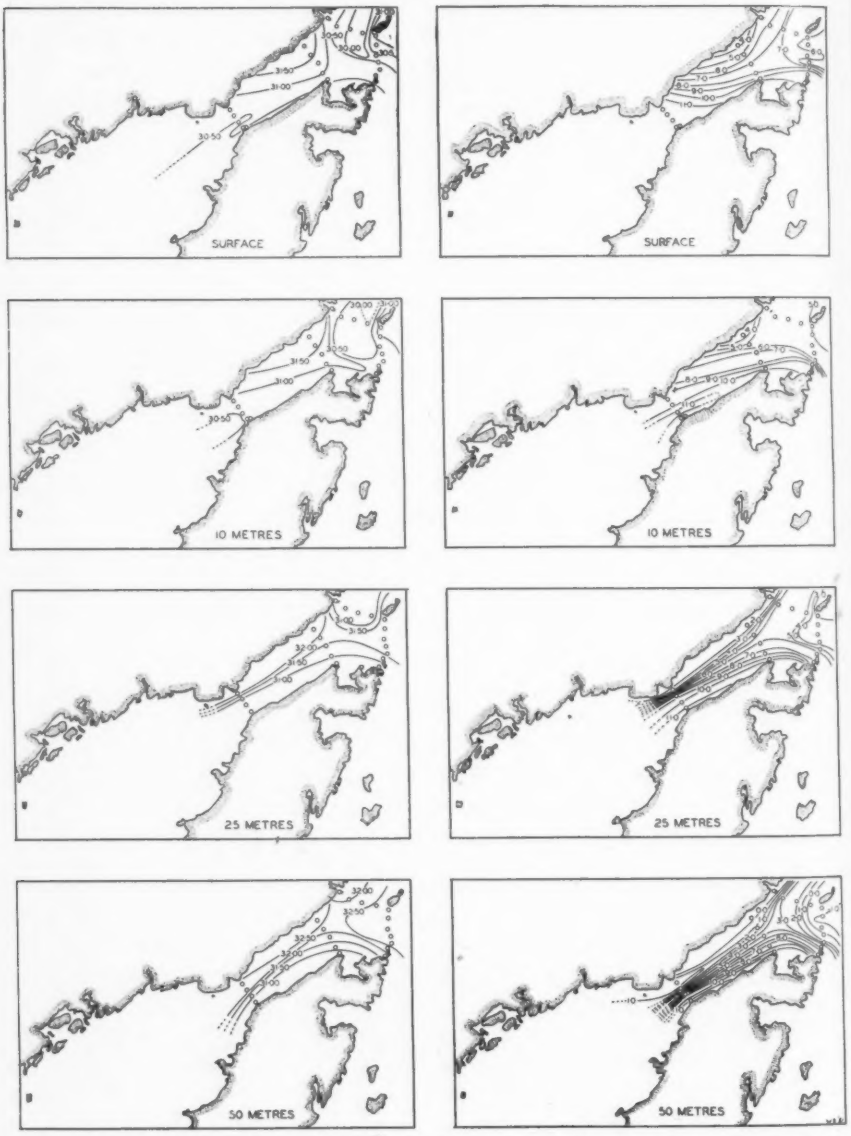

FIGURE 16. Distribution of temperature and salinity in Belle Isle Strait, September 7, 1923.

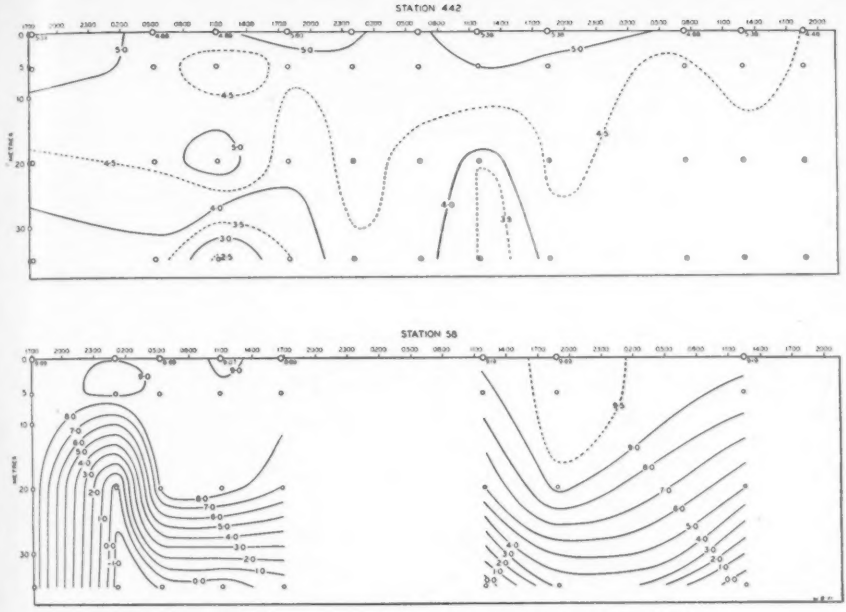

FIGURE 17. Temperature-time variations at stations 442 and 58.

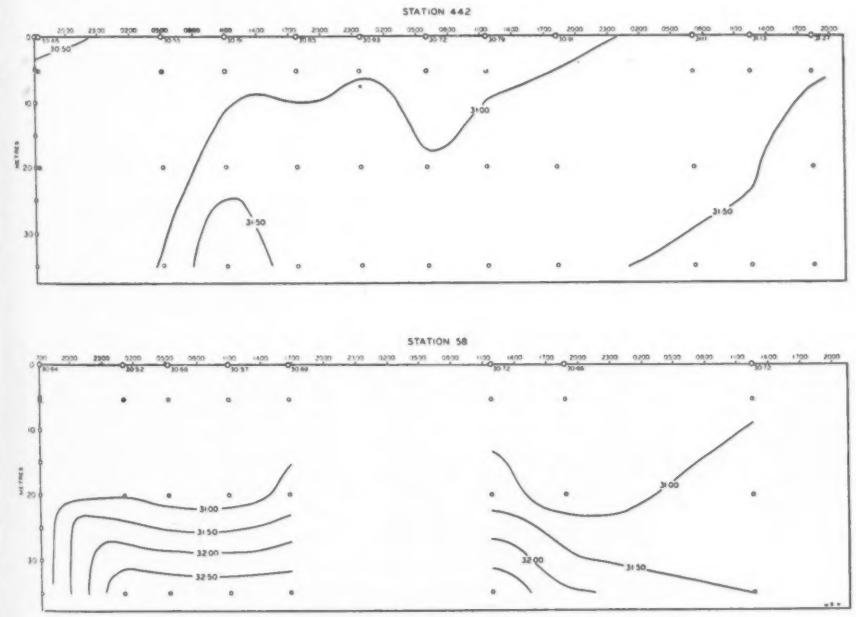

FIGURE 18. Salinities-time variations at stations 442 and 58.

salinities suggests that these are related directly to tidal influences. The waters on opposite sides of the Strait, during this series of observations, are from different water masses, that on the north side having the characteristics of the water north of Belle Isle (Bailey and Hachey, 1951) and that on the south side, the characteristics of the waters of the Gulf of St. Lawrence (Lauzier, Trites and Hachey, 1951).

Considering the extensive variation in the nature of the waters in the Strait of Belle Isle, as illustrated by the observations throughout the period August-September (Figures 3–18), it is to be appreciated that this time series of observations illustrates only one phase of the changing conditions in the water of the Strait of Belle Isle.

T-S Relationships

In Figure 19, the T-S diagram based on all the observations made in and

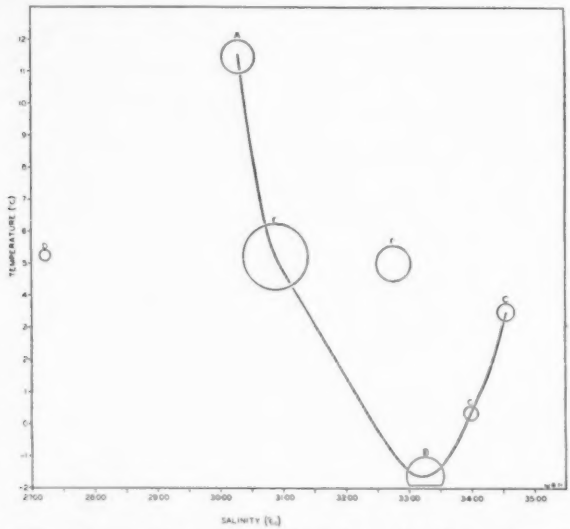

Figure 19. Temperature-salinity relationships from the observations of the Belle Isle Strait Expedition of 1923.

adjacent to the Strait of Belle Isle is illustrated. The main water masses involved in the diagram as well as the main water masses that do not enter are indicated by circles.

The T-S diagram indicates that the waters in and adjacent to the Strait of Belle Isle are, in general, composed of three different water masses, as follows:

(1) A-water, with temperatures greater than 11.0°C. and salinities of approximately 30.5‰, found in the upper 25 metres in the western portion of the Strait and in the Gulf of St. Lawrence, has the characteristics of waters from the surface layer of the Gulf of St. Lawrence.

(2) B-water, having temperatures and salinities of approximately −1.6°C. and 33.3‰, respectively, is true Arctic water, as previously described.

(3) C-water, exhibiting temperatures and salinities generally greater than 3.5°C. and 34.5‰, respectively (also previously described), is Labrador Sea water modified by waters of the West Greenland Current (3.5°C., 34.8‰) (Smith, Soule and Mosby, 1937). This water mass is not found in the Strait as such.

In addition to the above mentioned water masses, there are four distinct water masses that show influence of varying degrees upon the waters in the Strait, as follows:

(4) D-water, with temperatures and salinities of 5.0°C. and 27.2‰, respectively, found at the surface, is Labrador coastal water that has been chiefly influenced by land drainage.

(5) E-water, having temperatures between 4.5° and 6.5°C. and salinities between 30.5 and 31.5‰, found in the surface layer, is Labrador coastal water (Bailey and Hachey, 1951). This water comprises the greater portion of the surface waters on the northern side of the Strait and near Belle Isle.

(6) F-water, exhibiting temperatures from 5.0° to 6.0°C. and salinities from 32.5 to 33.1‰, as previously mentioned, comprises the surface layer at all stations across the Labrador Current, with the exception of station 45 (Figure 2). This water mass has the characteristics of the surface waters of the Labrador Current, which exhibits normal seasonal changes in its southward progress (Bailey and Hachey, 1951).

(7) G-water, with a temperature of 0.5°C. and salinities between 33.8 and 34.1‰, found at the greater depths in the Labrador Current, is Labrador Sea water (Dunbar, 1951).

In addition to the mixing that takes place between the different water masses that fall on the T-S curve there is evidence of direct mixing between the isolated water masses and those on the T-S curve. A-water mixes with B-water, D-water with E-water, and F-water with B-water. There is, however, no evidence of E-water mixing with F-water.

Current Measurements

As was stated previously, the Expedition had as its main object simultaneous observations of the current on the two sides of the Strait, which required two vessels to be anchored, one on each side, during the whole period of observation.

The current measurements were made from August 24 to 28 with the *E. E. Prince* anchored at station 442 and the *Arleux* anchored at station 58 (Figure 2). The plan included taking current measurements and direction of flow for ten minutes at each of 5.4, 20 and 35 metres depth every hour. Air temperature, surface temperature, velocity and fog conditions were to be recorded every half-hour. In addition plankton tows and hydrographic observations were to be taken four times daily. Difficulty was experienced in carrying out this plan.

A particular difficulty that was encountered in making current observations

was the continual breaking and fouling of the suspension cable for the current meter. Also it was found that bifilar suspensions and the slow movements of the vessel increased the reading of the meter.

The data obtained from the current meter, taken over a 72-hour period, are plotted in Figure 20. The results may be summarized as follows:

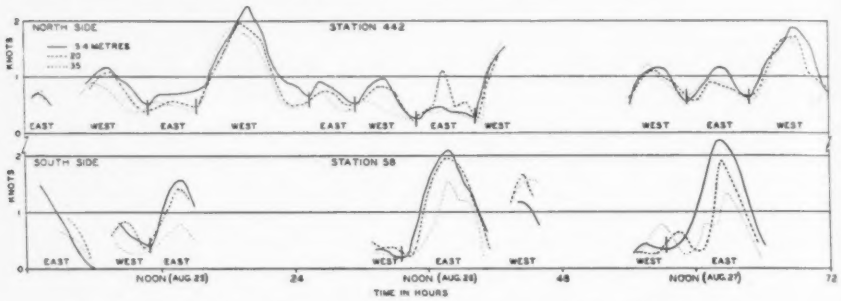

FIGURE 20. Results of current measurements, August 24–27, 1923, in the Strait of Belle Isle.

(*a*) On the north side of the Strait of Belle Isle, at station 442, the westerly currents were much stronger than the easterly currents. On the afternoon of August 25, for example, the flood or westerly set lasted approximately eight hours, with an average rate of about 2 ft./sec. or 1.2 knots. On the preceding ebb or easterly set, which lasted approximately five hours, the average rate of flow was 1.1 ft./sec. or 0.7 knots. Thus, it has been calculated that over the double tidal period there was a residual westerly trend of approximately nine miles (16.7 km.) per day.

(*b*) On the south side of the Strait of Belle Isle, at station 58, the easterly currents were much stronger than the westerly currents. On the afternoon of August 27, for example, the ebb or easterly set lasted approximately seven hours, with an average rate of 1.9 ft./sec. or 1.2 knots. On the preceding flood or westerly set, which lasted approximately four hours, the average rate of flow was 0.8 ft./sec. or 0.5 knots. It has been calculated that over the double tidal period there was a residual easterly trend of approximately eight miles per day.

The above current observations are in conformity with the results obtained from the general analysis of the hydrographic data recorded in foregoing pages, which indicated that during the period of the survey there was:

(*a*) a progressive inward movement of water of Arctic and sub-Arctic origin on the north side of the Strait, and

(*b*) a progressive outward movement of Gulf water on the south side of the Strait.

That there should be movements of the water inward along the north shore and outward along the south shore of eight or nine miles (14.8–16.7 km.) per day is not surprising, since, superimposed on the hydrodynamical and extraneous

forces acting on the water, is the differential effect of the earth's rotation. The deflecting force of the earth's rotation acting on a dominant outward flow from the Gulf would tend to produce the greater flow outward along the south shore; whereas when it acts on a dominant inward flow to the Gulf, the greater flow would be inward along the north shore. When the flow is to and fro on a tidal basis, the differential effect, as observed in the current measurements, must be the result.

In the introduction to this paper, the general views of Dawson (1927) are discussed, and it is sufficient to record that the "overall differential" between the north and south sides of the Strait is a feature of the water movements in the Strait of Belle Isle, even though masked to some extent by the dominant flow, which as Dawson has shown, is associated with wind and atmospheric pressure gradients.

Although a dominant flow of water into the Gulf was not observed throughout the period of observation, the conditions observed on August 16 when the expedition first reached the Strait were the result of an earlier predominant movement westward through the Strait. Icebergs were unusually abundant, the water had been unusually cold, the summer was very backward and the cod fishery the worst in years, as reported for Blanc Sablon on the north side of the inner end of the Strait. Eastward through the Strait, icebergs were absent only near the south shore at the inner end, and here alone warm water with Gulf plankton was found. This tongue of warm water, free from icebergs, extended only part way out through the Strait along the south shore.

Drift-bottle Experiments

Drift bottles were put out in series along strategic lines to reveal the water movements. Wind, however, interferred with the success of such a surface device. A series put out across the inner end of the Strait from Savage Cove to Point Amour on August 7 was exposed to stormy weather from August 8 to 11, with wind going from southwest to east through the north, and blowing a gale from the north for two days. The only returns were from bottles put out within two and three miles of the north shore, one of which went into the Gulf and reached the west coast of Newfoundland at St. Barbe by August 21, the other reaching St. Anthony on the outer coast by September 21. Four other series were put out on August 18, 19 and 21. On August 22, the barometer fell rapidly; and at Red Bay there was a gale from the north all day on August 23, which clearly shifted icebergs and their fragments to the south side of the Strait. Of 200 bottles put out along a line for 50 miles across the Labrador Current from Battle Harbour on August 18, all the returns from more than four miles out were from Europe in 1924, 1925 and 1926 (Iceland, Norway, Scotland, Ireland and England; 14 in all). Three returns from four miles out or less (Figure 21) show movement into and through the Strait. Of 72 bottles put out on August 19 along a line from Chateau Bay to Belle Isle, that is, in the course by which the Labrador Current enters the Strait (Figure 22), 14 were returned of which only three came from places outside the Strait. The others were reported from various places in the Strait, in the Esquiman

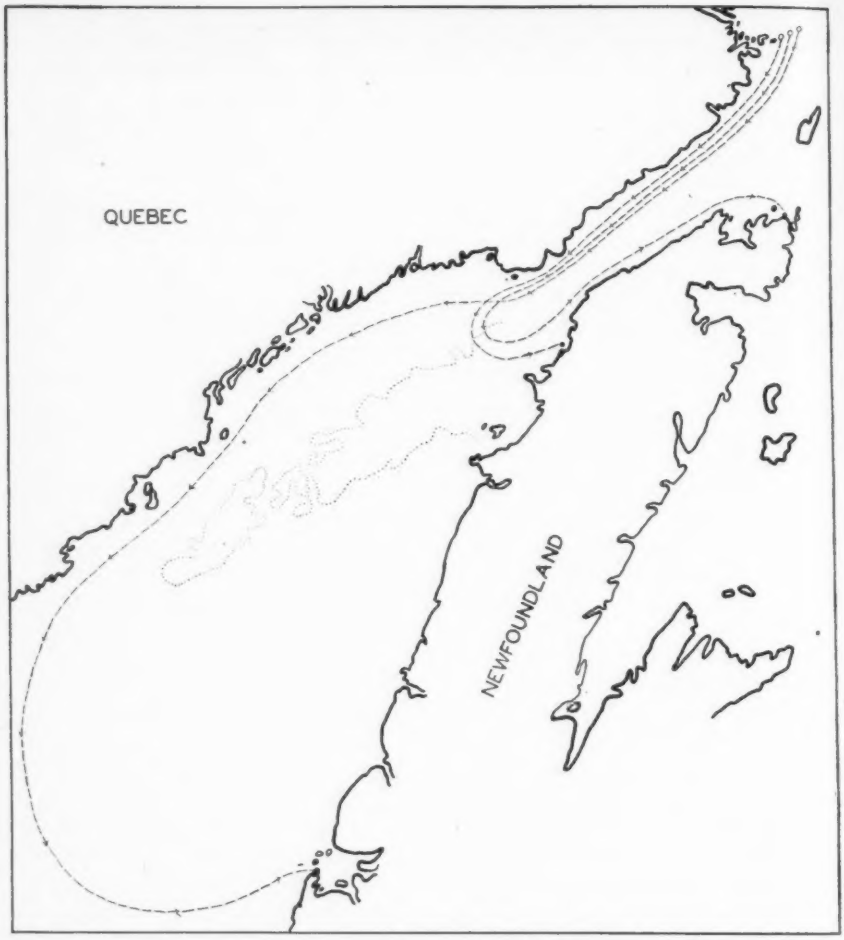

FIGURE 21. Interpretation of courses taken by drift bottles set out from Battle Harbour, Labrador, eastward on August 18, 1923.

Channel and one from Grande Romaine, far in the Gulf along the north shore. Of 60 bottles, also put out on August 19, along a line from Belle Isle south to Cape Bauld, that is, across the course by which the water along the south shore of the Strait evidently passes out into the Atlantic, only three were returned, one of the first lot from Belle Isle the next day and two from the middle of the series from Ireland in 1924 and France in 1925. Of 64 bottles along a line across the Strait at the outer end from Cape Norman to Wreck Cove on August 21 (Figure 23), eight were returned, of which only two in the middle had passed through the

Strait. Three from the north shore (within four miles) reached the outer coast of Newfoundland, but doubtless went at first for some distance into the Strait.

In July, bottles were put out to show the circulation in the Esquiman Channel. Of 252 bottles in a line across Cabot Strait from White Head, Cape Breton, to Port-aux-Basques, Newfoundland, on July 8, only 11 were returned. Of these, only one had entered the Gulf. It was found in November at Port-au-Port on the west coast of Newfoundland. However, of 496 bottles put out by Mr. G. F. Sleggs in a line across Cabot Strait from North Sydney, Cape Breton Island, to Port-aux-Basques, Newfoundland, on July 6 and 7, 1922, 131 were returned. Their distribution (Figure 24) shows a very definite movement inwards on the

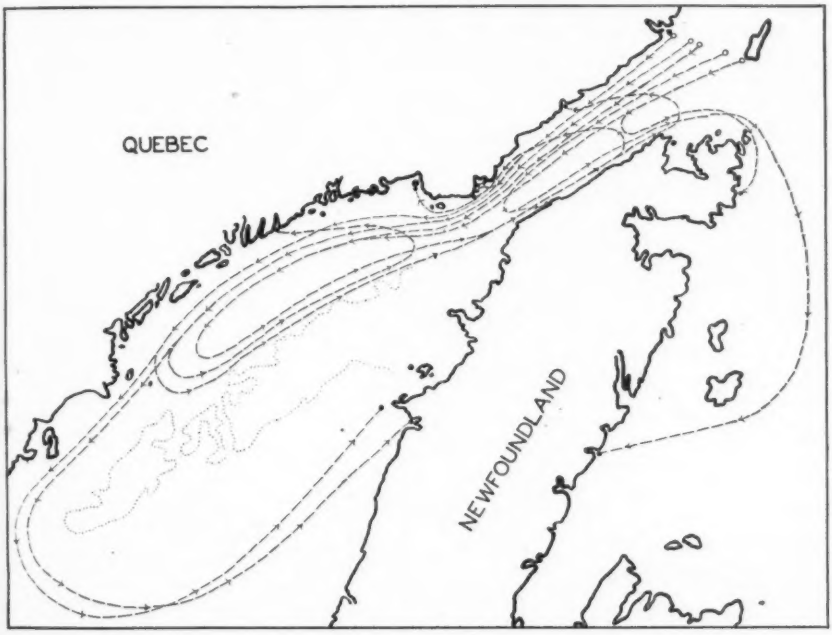

FIGURE 22. Interpretation of courses taken by drift bottles set out between Chateau Bay, Labrador and Belle Isle, on August 19, 1923.

north side and northeastward along the west coast of Newfoundland to the inner end of the Strait of Belle Isle. There was outward movement on the south side, and in the middle an evident whirling from one side to the other, with most of the movement outward. The striking difference in distribution of the returns between 1922 and 1923 is clearly due to the wind. In 1923, there was at Port-aux-Basques a northeast wind of 48 miles an hour both at 9 a.m. and at 9 p.m. and winds from north and northwest the next day. These would drive the bottles across the Strait toward the Cape Breton side and then emphasize the outflowing Cape

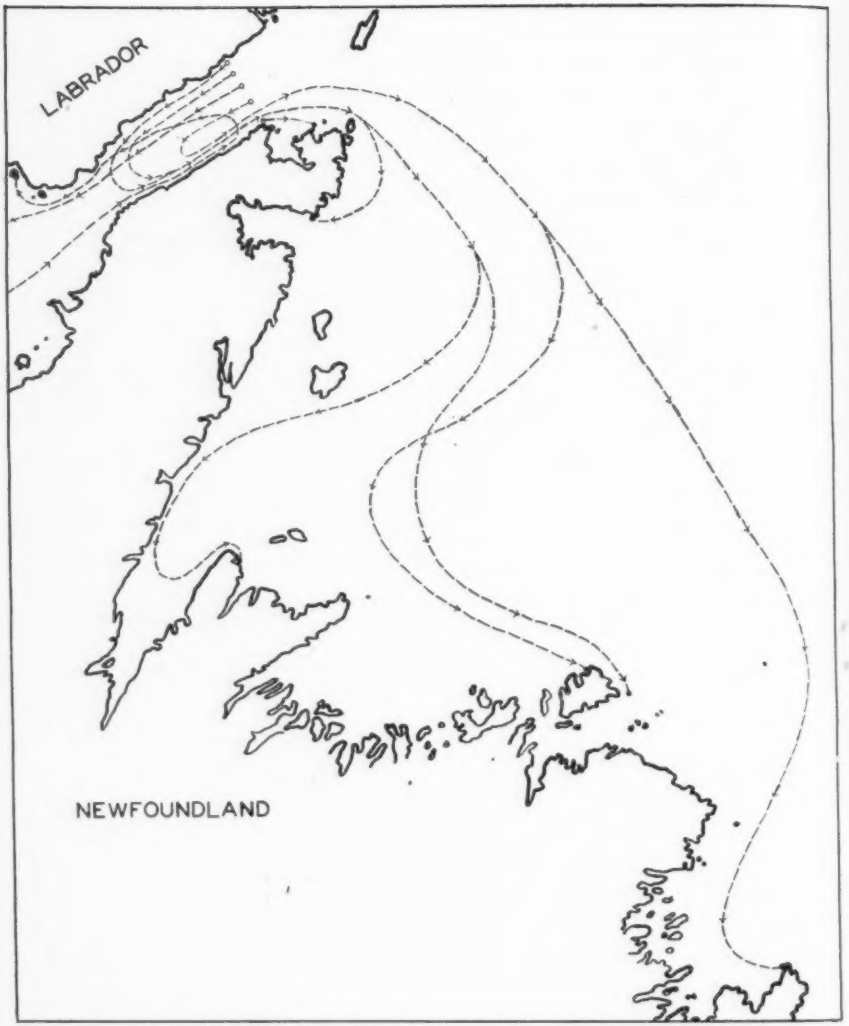

FIGURE 23. Interpretation of courses taken by drift bottles set out between Cape Norman, Newfoundland, and Wreck Point, Labrador, on August 21, 1923.

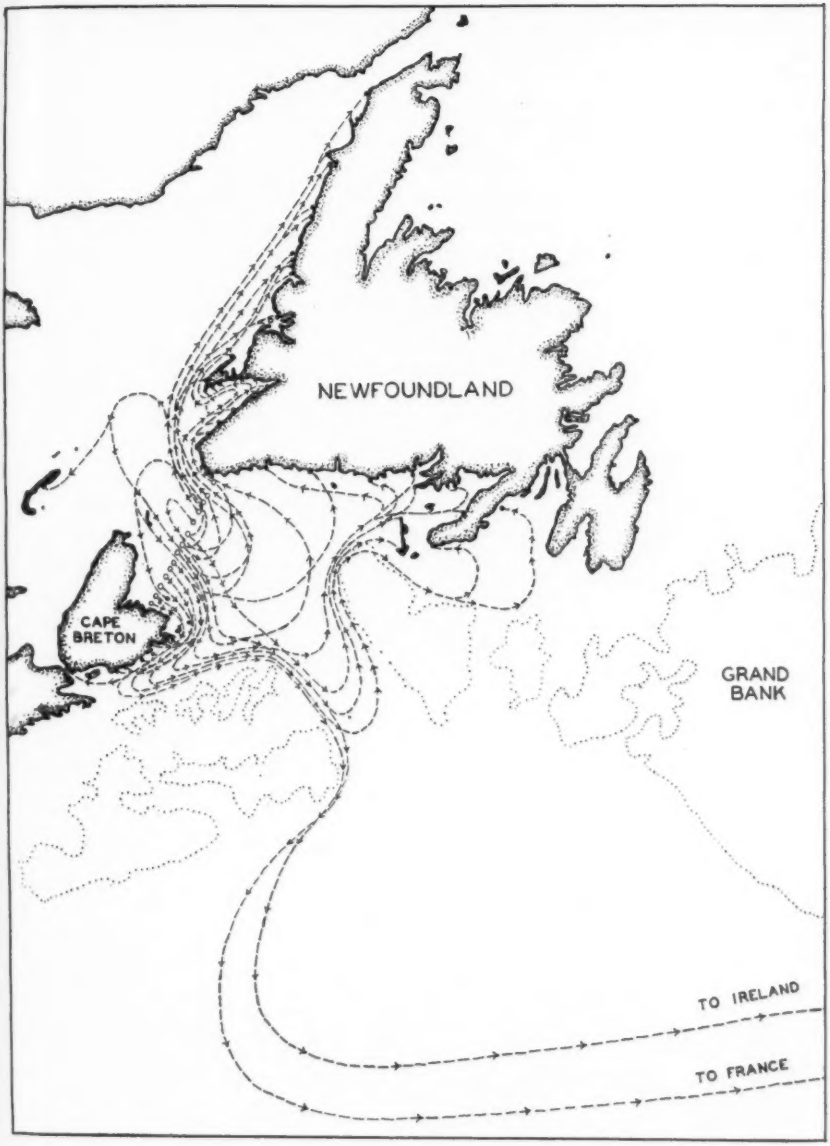

FIGURE 24. Interpretation of courses taken by drift bottles set out between Sydney, Cape Breton, and Port-aux-Basques, Newfoundland, on July 6 and 7, 1922.

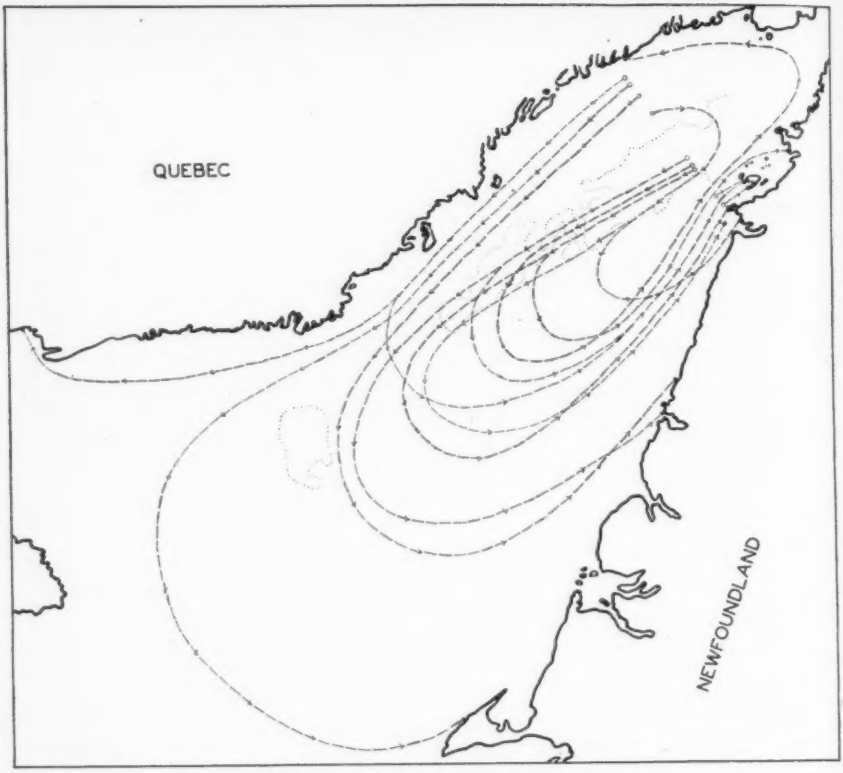

FIGURE 25. Interpretation of courses taken by drift bottles set out between Point Rich, Newfoundland, and Lobster Bay, Quebec, on July 31, 1923.

Breton Current. In 1922, winds from the southeast prevailed for a week after the bottles were put out. Of 174 bottles put out in a line across the Esquiman Channel from Point Rich to Lobster Bay on July 31 (Figure 25), 20 were returned. Within eight days, five from near Point Rich reached St. John's Island to the north along the coast. Within 36 days, four others from other parts of the line reached the district near Point Rich both south and north. The seven later returns in the year were from this same locality and also more widely scattered points around the Channel; one came from the north shore of the Gulf opposite Anticosti Island. The remaining four returns were in later years, two from the two sides of the Channel and the others from Ireland and Scotland.

The water movements shown by drift bottles in the Esquiman Channel correspond with those of Dawson's current measurements, the most pronounced surface current being northeastward along the Newfoundland shore at Point Rich, which is in accordance with the action of the prevailing southwest winds of summer. The bottles put out across the two ends of the Strait showed move-

ment in both directions through the Strait in harmony with what was found otherwise. The series across the Labrador Current out from Battle Harbour showed only the inshore water reaching the coast to the south (Figure 20), which is as expected. Although no movement into the Strait was shown by this series, the series between Belle Isle and the Labrador coast gave much more evidence of movement into and through the Strait than of movement southward past the Strait. The series between Belle Isle and Newfoundland gave movement outward only, in accordance with expectations. It is noteworthy as reflecting the diversity of the movements presumably effected by wind, that bottles going out from the Strait from the last series failed to reach the east coast of Newfoundland, while the comparable ones of the previous series, although put out on the same day, were reported mainly from the east coast.

THE ESQUIMAN CHANNEL

The Esquiman Channel may be defined as extending from the central portion of the Gulf of St. Lawrence between Cape Whittle, Quebec, and Bay of Islands, Newfoundland, northeastward to the inner end of the Strait of Belle Isle between Blanc Sablon and St. Barbe Bay. It is more than 100 fathoms deep, except as it approaches the Strait. However, the deep water is divided obliquely into two parts by a broad bank, less than 50 fathoms deep with patches less than 20 fathoms deep, which extends for the greater part of length of the Channel roughly along a line from Cape Whittle to St. Barbe Bay. This bank connects with the Newfoundland side a short distance north of Rich Point. The deep water north of this Mekattina Bank, which may be called Mekattina gully, is near the Quebec coast and isolated from deep water elsewhere. The deep water south of this Bank, which may be called Rich Point gully, is near the Newfoundland coast and connects with the deep Laurentian Channel which extends from the open ocean south of Newfoundland through the Gulf of St. Lawrence estuary.

Currents

Dawson (1897) measured the currents of the Esquiman Channel at three different points off the Quebec shore, off Cape Whittle, off the Mekattina Islands and off Mistanoque, and at two different points off the Newfoundland shore, off Cow Head and off Rich Point. The most definite movement was a rather steady current of one knot to the northeastward off Cow Head. The next most definite movement was a frequent or usual undercurrent to the southwest off Mistanoque and off the Mekattina. Off Rich Point, there is a preponderance of northeastward movement, and off Cape Whittle of southwestward or westward movement, the latter not as great as that on the Newfoundland coast. Dawson (1913) summarizes the situation as being a movement northeastward along the west coast of Newfoundland, which is stronger near shore, and a general movement of the body of the water westward along the north shore of the Gulf. Such circulation of the water suffices to explain the conditions observed.

From the facts given it is evident that the background for the circulation is the action of the Coriolis force in deflecting water movements to the right, such

movements consisting of the ebb and flow of the tides and the currents caused by winds, which are mainly from the southwest in summer. The trend of the Channel from southwest to northeast permits extended movements in those directions. The Mekattina gully permits a deep flow southwestward along the Quebec shore. The Mekattina Bank, by joining the Newfoundland shore north of Cape Rich, prevents more than a superficial current passing further to the northeast. The Strait of Belle Isle furnishes water, cold from containing a contribution from the Labrador Current, to the Quebec side of the Channel. The Strait also removes superficial warm water that reaches it along the Newfoundland side of the Channel. The Mekattina Bank deflects toward the Quebec side of the Channel much of the water that reaches Point Rich in passing northeastward along the Newfoundland coast.

The northeastern part of the Gulf may be considered to consist roughly of two large eddies, one south and the other north of the Mekattina Bank. In each, the water circulates contraclockwise. The eddy around the Mekattina gully receives at the northeast a mixture of water from the Labrador Current and from the Mekattina Bank close to the west coast of Newfoundland. At the southwest it discharges this mixture past the western end of the Bank into the eddy around the Point Rich gully. This eddy receives very different water at the southeast, which has come along the west coast of Newfoundland from the north side of Cabot Strait. At the northeast, the eddy around the Point Rich gully loses water superficially over the Bank. What it receives from the other eddy at the western end of the Bank is mixed with water coming from Point Rich along the south side of the Bank, which changes the character of the water on the Quebec shore west of Great Mekattina Island. The summer influence of the Labrador Current is much ameliorated at Bradore Bay just inside the Strait by mixture with water from the Newfoundland coast and it is ameliorated again at Great Mekattina through further mixture of water from the Newfoundland coast.

Vertical Distribution of Temperature, Salinity and Density in Section

The locations of hydrographic stations occupied between August 7 and 17, 1923, in Esquiman Channel and Cabot Strait are shown in Figure 26. The vertical distribution of temperature, salinity and density in the Esquiman Channel and Cabot Strait are shown in Figures 27–30.

In Figure 27, the vertical distribution of temperature (A), salinity (B) and density (C), for August 7, 1923, is illustrated for the section across Cabot Strait between Cape Ray, Newfoundland, and Cape Egmont, Cape Breton Island.

The most striking hydrographic feature of this section is the intense stratification of the upper 50 metres in temperature and salinity. Temperatures range at Station 1 from 15.0°C. at 25 metres to 0.0°C. at 70 metres with corresponding salinities of 23.5 and 33.0‰, respectively. A body of Arctic water, with temperatures less than —1.0°C. and salinities between 32.5 and 33.0‰, is seen extending from the Newfoundland shore to the centre of the Strait.

Below the 165-metre level, the influence from the Atlantic is in evidence, with the water warming from 0.0°C. at 165 metres to 3.0°C. at 295 metres. Below

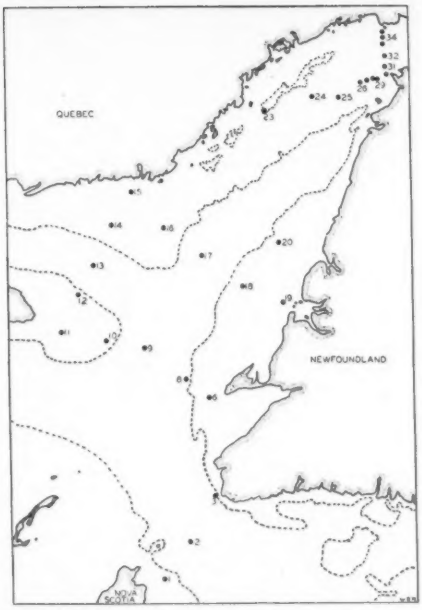

FIGURE 26. Locations of hydrographic stations in the Esquiman Channel. Dashed line shows the shape of 100-fathom contour.

the 300-metre level the waters are more homogeneous and show little variations with depth in temperature and salinity.

The dynamic tendencies, as indicated by the slope of the isopycnals, are such that the lighter surface waters to a depth of nearly 50 metres are moving eastward throughout the entire section. The eastward tendency reaches to a depth of 70 metres between stations 1 and 2. However, between stations 2 and 3 a westward tendency is in evidence between the 50- and 150-metre levels. This westward movement reaches across the entire section below the 100-metre level. Since below 150 metres there is only a single set of observations, it is impossible to determine the relative slopes of the isopycnals below this level.

Thus it is seen that warm surface waters are moving out of the Gulf, the strongest movement being in the Cape Breton shore, and the cold waters of Arctic again are moving into the Gulf, mainly on the Newfoundland shore.

The vertical distribution of temperature (A), salinity (B) and density (C) for the section between Cape St. George and Heath Point is given in Figure 28. Notable features of this section are the well-developed surface layer extending to a depth of 10 metres, with temperatures generally greater than 11.0°C., the marked thermocline with a gradient of 1.0°C. per metre and the large volume of cold water less than 0.0°C. with a minimum temperature of −1.58°C., lying between the 25- and 200-metre levels at station 10, and between the 70- and 150-metre levels at station 8. Corresponding salinities range from 32.5 to 33.5‰.

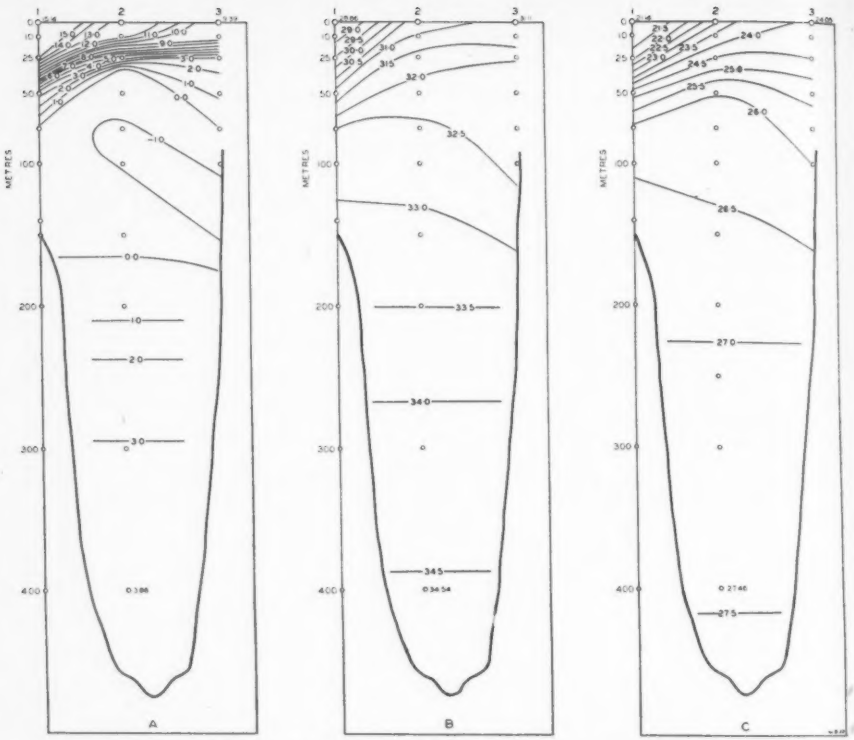

FIGURE 27. Distribution of temperature (A), salinity (B) and density (C) in section between Cape Egmont, N.S., and Cape Ray, Newfoundland, August 7, 1923.

Below the 200-metre level the temperatures are generally greater than 1.0°C. with salinities greater than 33.5‰, and as high as 3.9°C., with a salinity of 34.0‰ at 235 metres at station 9.

The slopes of the isopycnals are indicative of two distinct water movements in the upper 100 metres, and a third below 150 metres. One between stations 10 and 11 shows a southward tendency, and the other between stations 6 and 9 shows a northward movement, both movements reaching to a depth of approximately 100 metres. The slope of the 27.0 isopycnal at about the 200-metre level indicates a general northward drift throughout the entire section.

Figure 29 shows the vertical distribution of temperature (A), salinity (B) and density (C) in section between Heath Point, Anticosti Island, and Cape Whittle, Quebec. This section has the same features as the one previously discussed in the Gulf of St. Lawrence, with the water masses exhibiting the same general characteristics.

In the slope of the isopycnals, it is evident that the general overall water movement is to the westward, and is most pronounced between stations 14 and

15. A notable exception occurs between stations 13 and 14, where in the upper 50 metres the slopes are indicative of an eastward movement.

In the section between Cape Whittle and Bay of Islands, the vertical distribution of temperature (A), salinity (B) and density (C) is shown in Figure

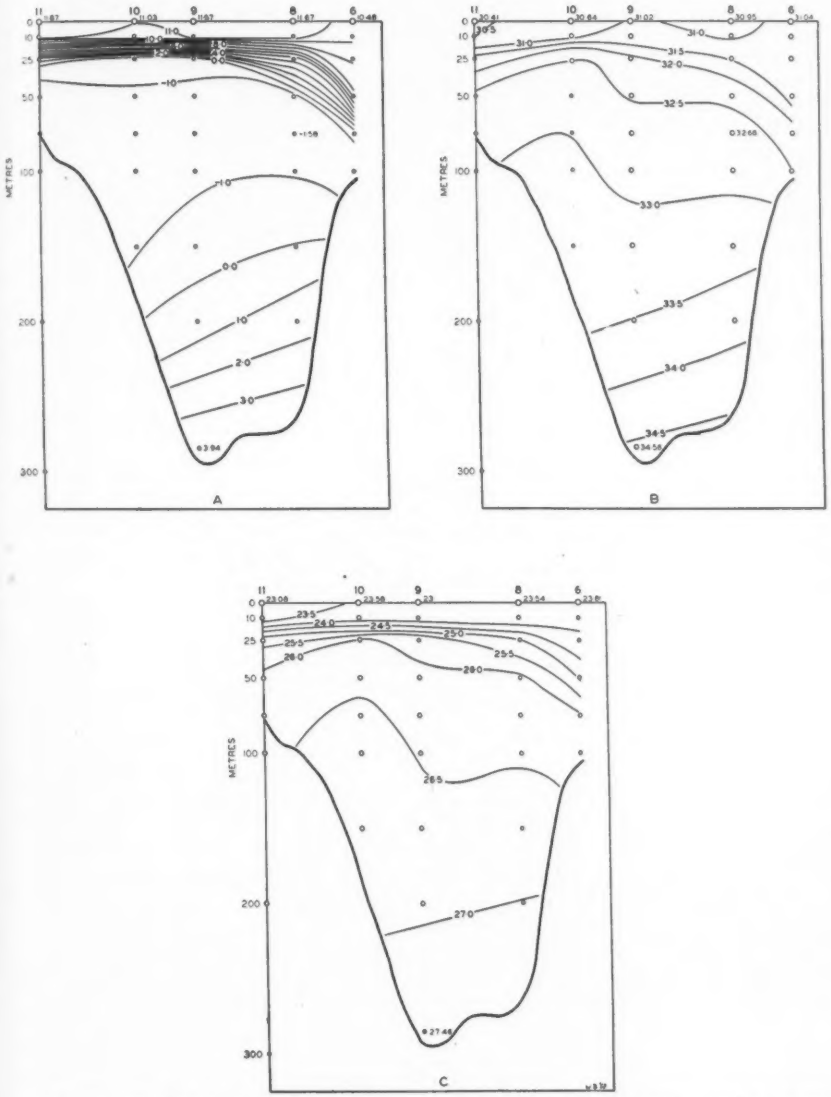

FIGURE 28. Distribution of temperature (A), salinity (B) and density (C) in section between Cape St. George, Newfoundland, and Heath Point, Anticosti, August 10–11, 1923.

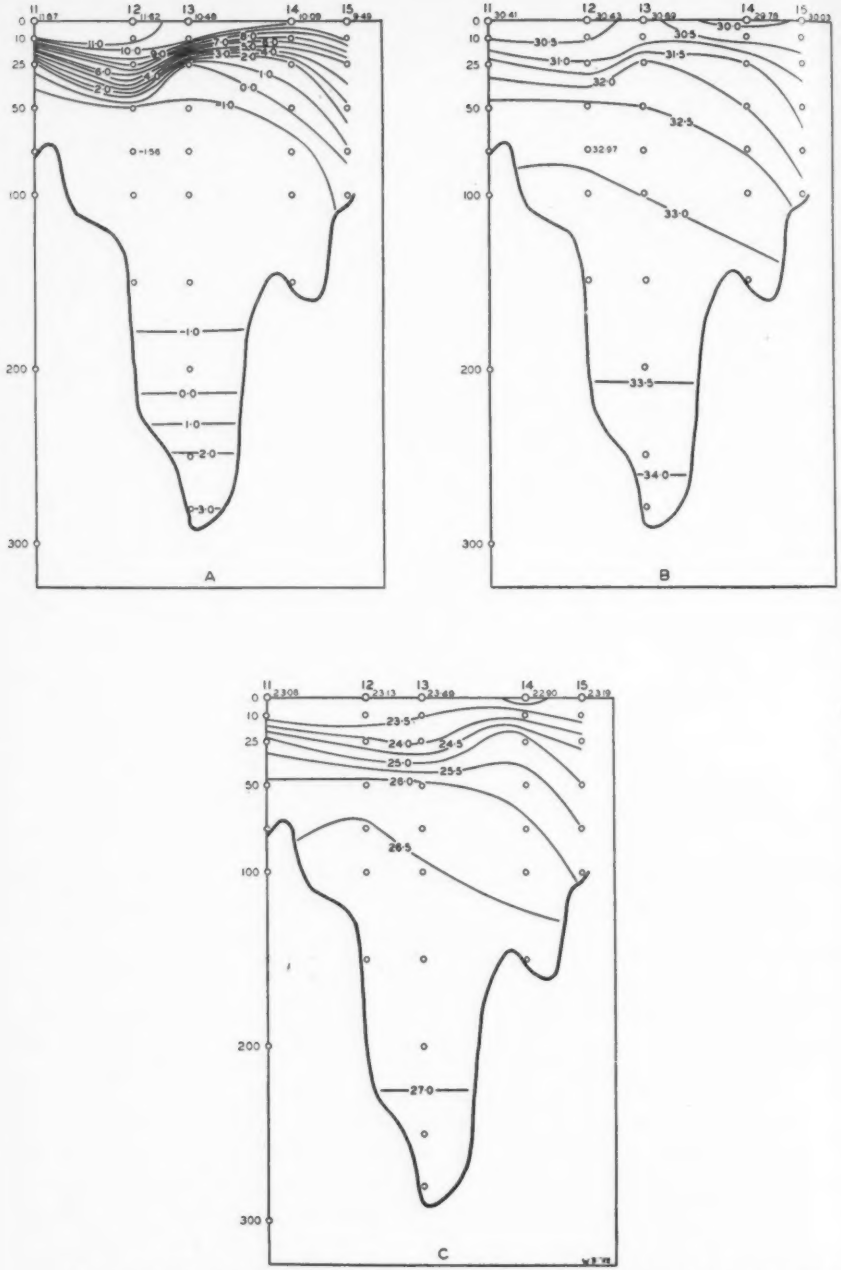

FIGURE 29. Distribution of temperature (A), salinity (B) and density (C) in section between Heath Point, Anticosti, and Cape Whittle, Quebec, August 11–12, 1923.

30. As in the other sections in the Gulf of St. Lawrence, a well-developed surface layer and a marked thermocline are in evidence. The cold water layer is seen to extend across the entire section with an average thickness of over 100 metres. The upper boundary (0.0°C. isotherm) varies considerably in depth, ranging from 80 metres at station 15 to 25 metres at station 18. A considerable portion of this cold water layer has temperatures less than —1.0°C. with a minimum of —1.37°C. Below the 200-metre level the waters have temperatures generally greater than 3.0°C.

From the slopes of the isopycnals, the main body of water between stations 15 and 18 has southward tendencies, whereas between stations 18 and 19, the tendency is northward. The low-density water is found, in the main, in the

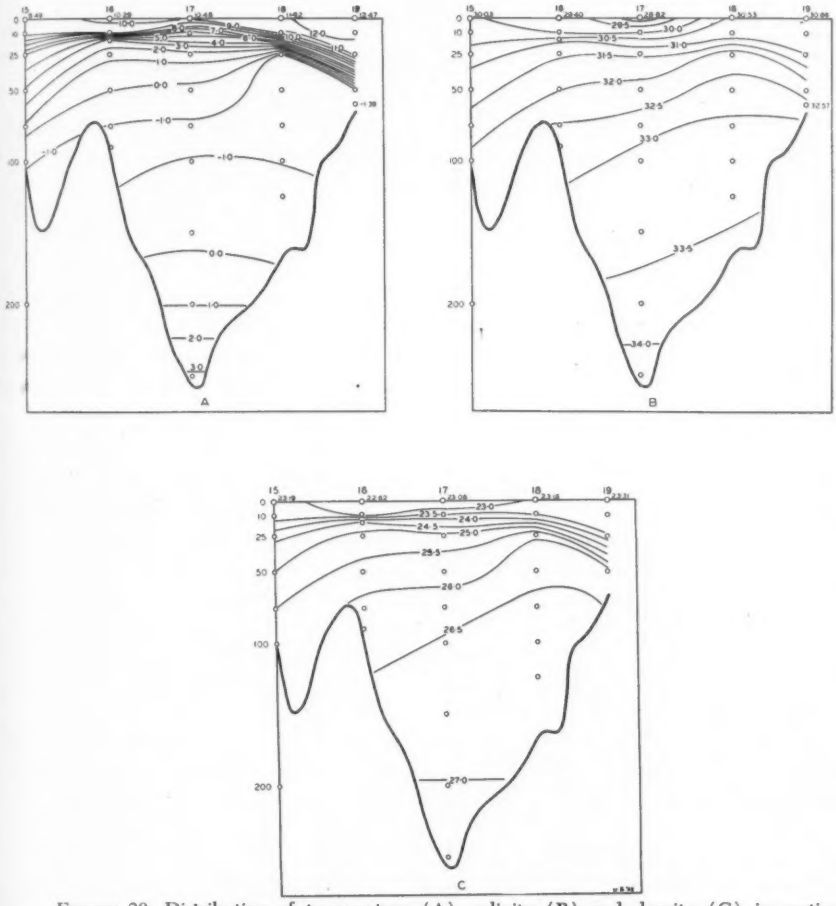

FIGURE 30. Distribution of temperature (A), salinity (B) and density (C) in section between Cape Whittle, Quebec, and Bay of Islands, Newfoundland, August 12, 1923.

western portion of the section with a minimum of 23.18 at the surface at station 15.

A fifth section has been described previously in the general treatment of the Esquiman Channel and its relation to the Strait of Belle Isle.

In reviewing the water movements, as indicated by the slopes of the isopycnals in the five sections in the Esquiman Channel and Cabot Strait, it is seen that the general circulation as presented by these sections agrees well with that presented by Sandstrom (1919) as follows:

(1) a strong inward movement through Cabot Strait on the Newfoundland side, and a strong outward movement on the Cape Breton side;
(2) a strong northeasterly movement along the west coast of Newfoundland; and
(3) a somewhat weaker westerly movement along the Mekattina shore and entering Jacques Cartier Passage.

The Horizontal Distribution of Temperature and Salinity

The horizontal distribution of temperature and salinity in the eastern part of the Gulf of St. Lawrence for the period August 7–16, 1923, is given for depths of 0, 25 and 50 metres in Figures 31–33, respectively. These diagrams include data that are presented in Figure 15; the two figures are thus complementary and assist in determining the relationship between the waters in the Strait of Belle Isle and in the Esquiman Channel.

The indraughts of water through Cabot Strait and the Strait of Belle Isle and their respective spreadings over the Esquiman Channel are clearly demonstrated by the horizontal distributions of temperature and salinity at this time. The outdraught of Gulf waters is also demonstrated, with the movement confined to depths of less than 50 metres in the Strait of Belle Isle.

T-S Relationships

Temperature-salinity curves are plotted for several hydrographic stations that may be involved in the general change of waters between the Strait of Belle Isle and Esquiman Channel. A somewhat general typing of the water masses was made in the previous section, which delineated the various water types that prevailed in the Belle Isle area. In an attempt to gain further information regarding particular relationships between the waters on either side of the Strait of Belle Isle, and on either side of the Esquiman Channel, selected stations have been plotted in Figure 34 to point out existing differences. The locations of the stations used are shown in Figures 2 and 21.

As previously pointed out, there is a notable difference in the salinity of the cold water on opposite sides of the Esquiman Channel (stations 431 and 427). Based on the horizontal distributions of temperatures and salinities, there are two main sources of water in the Esquiman Channel and the Strait of Belle Isle. By selecting two stations that may be considered representative of these two sources and plotting their T-S curves, we may trace the origin of the coldest water at each station. In Figure 30, station 2, in Cabot Strait, and station 47, north of Belle Isle, were plotted as being representative of the Cabot and Labrador

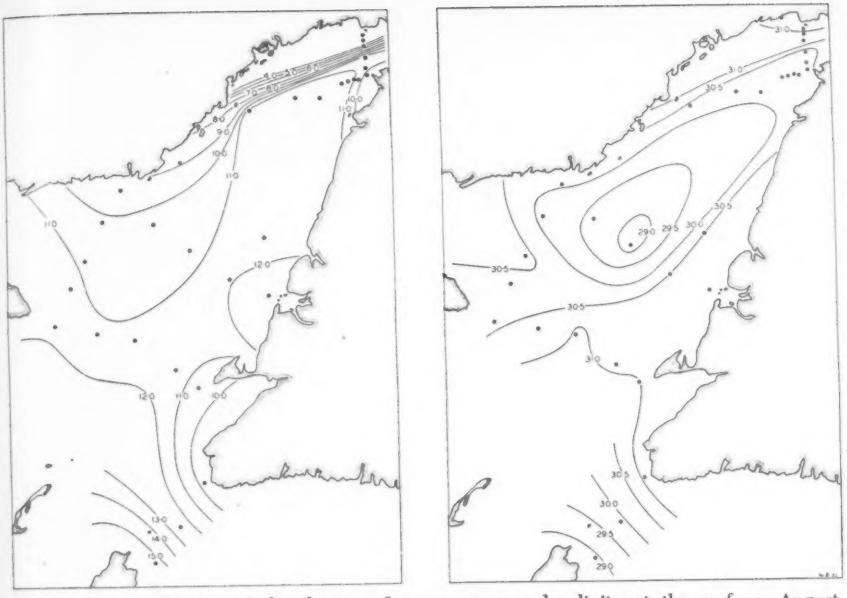

FIGURE 31. Horizontal distribution of temperature and salinity at the surface, August 7–17, 1923.

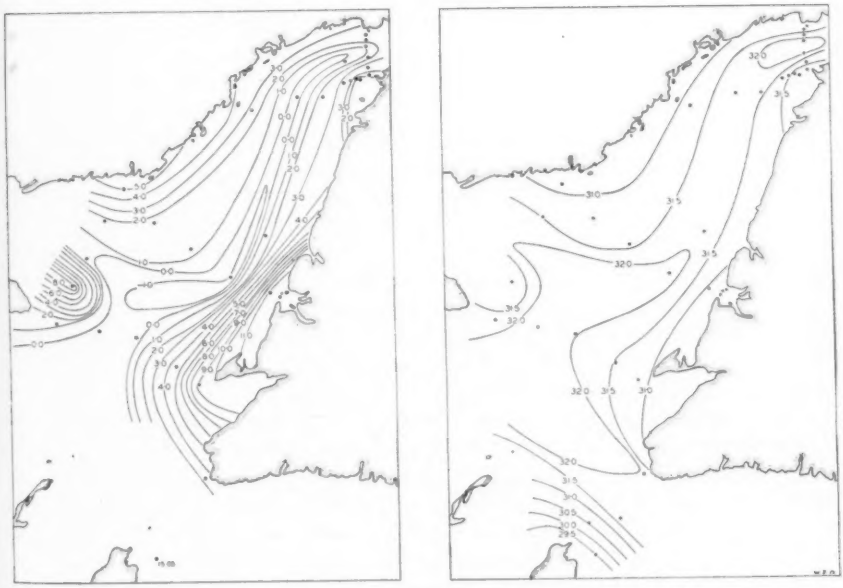

FIGURE 32. Horizontal distribution of temperature and salinity at 25 metres, August 7–17, 1923.

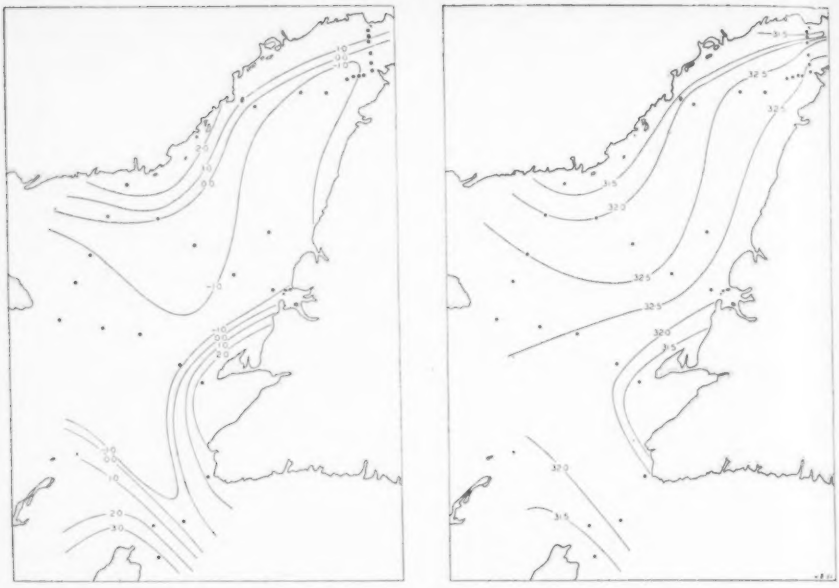

FIGURE 33. Horizontal distribution of temperature and salinity at 50 metres, August 7–17, 1923.

contributions, respectively. It was found by plotting the minimum temperature at each station, where the depth allowed sufficient observations for a good T-S curve, that, in general, stations on the north side of the Esquiman Channel fell on the T-S curve for station 47, and those on the south side fell on the curve for station 2.

It is of interest to note that the Arctic waters having the Labrador characteristics (−1.7°C., 33.2‰) always underlie those having the Cabot characteristics (−1.6°C., 32.7‰), and that the apparent source of the Labrador water, i.e. through the Strait of Belle Isle, is not continuous. This Labrador water type is not found, at this time, near the threshold level of the Strait. It must therefore be assumed that there was, at an earlier date, a considerable movement of Arctic water through the Strait of Belle Isle, probably in the late winter and early spring, the last vestiges of which are identifiable in the deep troughs along the north side of the Esquiman Channel. Its influence is shown by the shape of the T-S curve at station 13 which indicates the effect of the Labrador water.

In considering these T-S characteristics it is evident that the Arctic waters in the Esquiman Channel are at this time composed, in the main, of a mixture of two types of Labrador Current water, one that has been modified in its course around Newfoundland and the other that has presumably moved through the Strait of Belle Isle at some earlier date. This fact is borne out by the T-S curve of station 13 (between Anticosti and the north shore of Quebec) which joins the two water types.

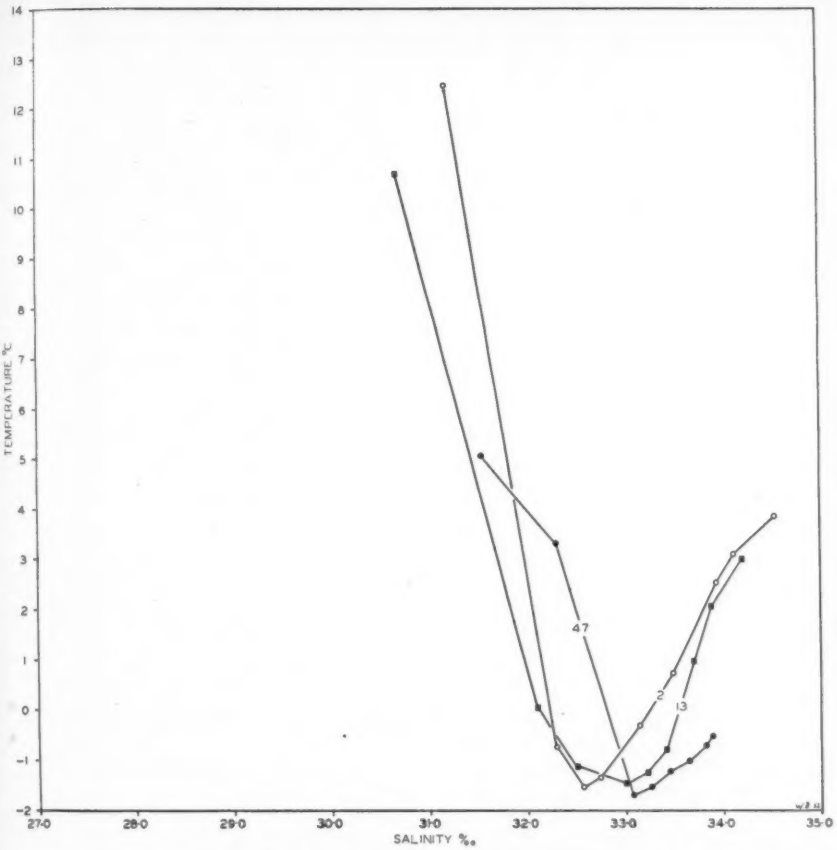

FIGURE 34. Temperature-salinity relationships of stations representative of waters found in the Esquiman Channel in August, 1923.

Undoubtedly much of the cold water layer with temperatures between −1.0°C. and 0.0°C. was formed locally during the winter months. This water would of necessity have salinities of approximately 32.0‰ or less (Lauzier and Bailey, 1952).

PLANKTONIC INVERTEBRATES

Certain animals that float in the water serve to show how it moves, that is, whence and whither they are transported by it. Arctic forms that do not reproduce in the region and that do not survive long at high summer temperatures show the courses taken by the water coming from the Arctic as the Labrador Current. Animals that reproduce in summer in the warmest of our coastal waters show the courses taken by such waters. Animals that live in northern oceanic water of high salinity show the courses of such water in penetrating our inland waters.

The plankton of the Belle Isle Strait Expedition has been studied by various investigators, and the most striking of their results in revealing the circulation of the water will be summarized.

The Arctic Ctenophore *Mertensia ovum* was believed to show movement of water from the Labrador Current in through the Strait of Belle Isle and along the north shore to the centre of the Gulf of St. Lawrence north of Anticosti Island, since it was found by the Canadian Fisheries Expedition of 1915 to occur north of Anticosti Island, but not elsewhere east, west and south in the Gulf. Its distribution in 1923 (Figure 35) accorded with this belief. It was found (Pinhey, 1927a, b) at every one of the nine stations across the Labrador Current, going outward to deep water from Battle Harbour (Figure 2). At the outer end of the Strait of Belle Isle, it was at all ten stations from Chateau Bay to Belle Isle and from Belle Isle to Cape Bauld except the last, which was close to Cape Bauld and had warm water evidently of Gulf origin. Similarly, in the Strait, at five stations from Wreck Bay on the north side to Cape Norman on the south side, it was absent only at the last, where there was warm water of Gulf origin. At the inner end on August 7, when icebergs showed that the whole width of the Strait had been occupied by water from the Labrador Current, it was at all five stations across the Strait. But, with movement of warm Gulf water out of the Strait later in August, it was found on September 7 only at the most northerly station of the same five, that close to Amour Point. Near the centre of the Gulf it occurred from Anticosti Island to Cape Whittle (*Arleux* stations 11 to 15) and halfway across the Esquiman Channel toward Bay of Islands (*Arleux* stations 16 and 17). It occurred at various stations on the outer coast of Newfoundland, and also at one on the south coast a short distance west of Cape Race. Its distribution clearly shows the extent of the movement of water from the Labrador Current along these two courses. Another Ctenophore, *Beroe cucumis*, showed a similar distribution, but the material studied (mainly No. 5-net tows) was not so suitable for it.

Among the Copepods the only species to have such a limitation to Arctic superficial water was *Acartia longiremis* var. *spiniremis*, and its numbers were low (Pinhey, 1927a, b). Across the Labrador Current it was in largest amount at the inshore station (45) as shown in Figure 2. At the entrance to the Strait of Belle Isle, it was at every station north of Belle Isle and also south, except that there were none close to Cape Bauld (station 78) and only one at the next station (77), these representing the warm water issuing from the Gulf. Similarly it was absent on the south side near Cape Norman (station 64), and only one was at the next station (65) in the section across the Strait where it narrows. Again, at the inner end of the Strait between Savage Cove and Amour Point, it was absent only from the two southern stations (*Prince* 408, 409), both on August 7 and September 7; and on the latter date there was only one at the next of the five stations (410). In the Esquiman Channel, it occurred only near the Quebec shore, at *Arleux* stations 57, 33, 22 and 15, except that it was at station 17 in the middle of the inner end or mouth.

Two species of Amphipods (Bousfield, 1951) reveal rather clearly the

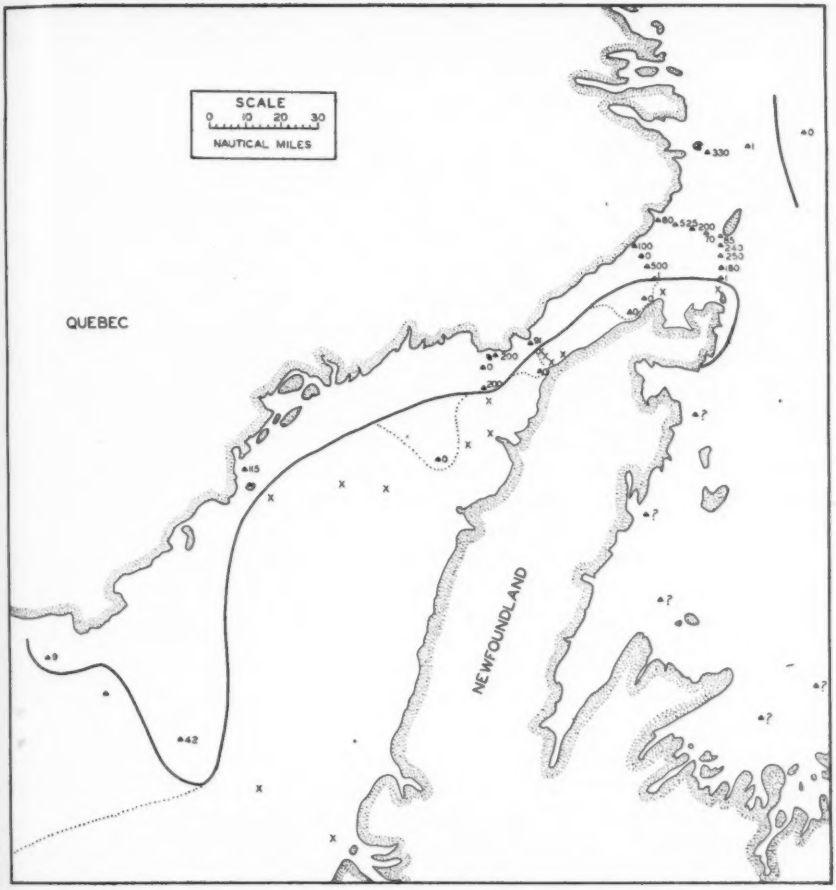

FIGURE 35. Distribution in the Strait of Belle Isle of *Mertensia ovum* (solid triangles) and of *Acartia spiniremis* (figures, representing numbers of individuals) in plankton tows with No. 5 net at about 7 metres depth in late August and early September, 1923 (data from Pinhey, 1927). Crosses represent stations where neither of these were taken. Continuous line represents limits for *Acartia* and dotted line more extended limits for *Mertensia*. These Arctic forms show by their presence movement of water from the Labrador Current inward along the north shore of the Strait and of the Esquiman Channel, and by their absence the movement outward from the Gulf along the south shore of warmer water that kills them.

extent of the influence of the Arctic water, although they were not very numerous. They tended to disappear when the surface water became warm at the end of the summer. As shown in Table I both species, *Themisto libellula* and *Pseudalibrotus glacialis*, are at the surface in daytime and in deeper water at night. Dunbar (1946) considers that "there is evidence . . . that the stronger the light the closer *Themisto* is found to the surface in daytime". The facts in Table I suggest

TABLE I. Depth distribution of *Themisto libellula* and *Pseudalibrotus glacialis*, as shown by tows taken at depths of 0 to 2 metres and 18 to 23 metres in 1923.

Hour	9–12	12–15	15–18	18–21	21–3	3–9
T. libellula						
0–2 m.	95	38	192	10	2	1
18–23 m.	7	0	3	0	18	20
P. glacialis						
0–2 m.	0	2	2	5	0	0
18–23 m.	10	3	4	0	1	5

that there is delay in reaching the surface and that the delay is greater for *P. glacialis* than for *T. libellula*. A substantial number of the latter, but not of the former, are at the surface before noon, and the former seem not to be fully at the surface until late in the afternoon. After dark both descend, but the former more completely. This behaviour seems referrable to the effect of light on their activity: They sink when inactive with low light, as deduced for *Calanus* (Cushing, 1951); they come to the surface when it is warmest at the end of the day's insolation.

They were generally across the Labrador Current out from Battle Harbour on August 18–19, but were absent on September 7 from the water between Belle Isle and both shores of the Strait, except one *T. libellula* at the station nearest the Labrador coast. The previous day, there were a few of this species across the Strait between Cape Norman and Wreck Cove where it narrows, but on the same day none were found in a series of stations across the inner end of the Strait. Nor were any found on September 10 and 15 at two stations on the Quebec shore inside the Strait. Along the east coast of Newfoundland during the second week in September, only several isolated individuals of *T. libellula* were found at 12 stations. The facts indicate that *P. glacialis* was wholly eliminated from the Labrador Current by September and *T. libellula* almost so. In August, however, they were both found not only in the current, but through the Strait and along the north shore of the Esquiman Channel to the central part of the Gulf.

The Appendicularian *Oikopleura vanhöffeni* has been used by Thompson and Frost (1936) as an indicator of the influence of the Labrador Current. It was found from the material of 1923 (Pinhey, 1927; Udvardy, MS) to be in the inner part of the Labrador Current and along the east cost of Newfoundland. In the Strait and in the Esquiman Channel, it was not limited to the north or Quebec side, although more abundant there. Its presence on the Newfoundland side of the Esquiman Channel at the south evidently resulted from its entering the Gulf on the north side of Cabot Strait. Individuals began to disintegrate on entering the mixed water of the Strait, but remained partially alive for transport over rather great distances (Udvardy, MS).

Species that survive for a long time or breed successfully in our waters as far south as the Gulf of Maine and Bay of Fundy are of little use as indicators of the influence of the Labrador Current, although characteristic of it. Such are the

TABLE II. Planktonic Crustacea near the north and south shores of the Strait of Belle Isle in 1923, as taken with the No. 5 net at about 7 metres depth at pairs of stations from the inner end on August 21 to the outer end on September 7. Data from K. H. Pinhey (1927a).

	Aug. 21		Aug. 26	Aug. 8	Aug. 26		Sept. 6		Sept. 7	
Station	57	55	37	43	442	58	68	64	69	78
Shore	North	South	North	South	North	South	North	South	North	South
Calanus	5,000	3,720	1,144	17,688	3,290	1,512	3,300	11,072	1,500	7,245
Pseudocalanus	2,900	6,355	566	2,068	6,590	15,984	5,150	11,520	1,780	28,980
Oithona	1,900	930	290	220	60	180	1,100	5,760	600	3,150
Acartia	200	0	0	0	0	0	100	0	80	0
Centropages	0	310	0	264	0	216	0	1,024	0	1,575
Temora	0	19,220	0	814	0	10,692	100	3,456	0	2,520
Anomalocera	0	3	0	3	0	0	0	1	0	1
Evadne	0	155	0	330	60	4,968	0	11,520	x	11,025
Podon	0	310	0	616	0	2,448	0	19,648	0	8,505

Copepods *Calanus*, *Pseudocalanus* and *Oithona* (Pinhey, 1927) and the Amphipod *Themisto compressa* (Bousfield, 1951). The Pteropods *Clione limacina* and *Limacina helicina* (Kerswill, 1940) similarly were found to be too generally distributed for use as indicators of Labrador Current in the Gulf of St. Lawrence although useful farther to the southwest around Nova Scotia. They were found generally in the Strait, in the Esquiman Channel, in the central portion of the Gulf, in Cabot Strait and on the south coast of Newfoundland.

When, in late August of 1923, there was no dominant flow through the Strait of Belle Isle in either direction, but a rather steady make of the water outward along the south shore and inward along the north shore, as demonstrated by simultaneous current measurements near each shore midway in the length of the Strait, there was a very marked contrast in the plankton that was being carried in opposite directions along the two shores. The data (Table II) show that *Calanus finmarchicus*, *Pseudocalanus elongatus* and *Oithona similis* were in both kinds of water, and, although characteristic of the Labrador Current, were in general more abundant in the water moving out through the Strait. *Acartia spiniremis*, however, was only in the water moving in on the north side. There were five kinds to show the contrasting condition, being almost or altogether confined to the water moving out; these are *Centropages hamatus*, *Temora longicornis*, *Anomalocera patersoni*, *Evadne nordmanni and Podon leuckarti*. At the inner end of the Esquiman Channel (Table III, stations 15–19) these forms, when

TABLE III. Planktonic crustacea at successive stations across the southwestern end of the Esquiman Channel between Cape Whittle, Quebec, and Bay of Islands, Newfoundland (stations 15 to 19); and obliquely across the middle of the Channel between Mekattina, Quebec, and Ferolle Point, Newfoundland (stations 22 to 30). Samples were taken with the No. 5 net at about 7 metres depth on August 12 and on August 15–16, 1923, respectively. Data from K. H. Pinhey (1926).

Station	15	16	17	18	19	22
Centropages	30	135	462	72	480	276
Temora	0	585	966	0	4,020	943
Anomalocera	0	0	0	108	1	0
Evadne	0	0	42	0	0	1,265
Podon	0	0	0	0	0	0
Station	23	24	25	26	28	30
Centropages	2,756	7,686	7,140	4,730	2,850	4,420
Temora	20,034	36,356	21,760	32,035	32,110	32,300
Anomalocera	0	3	632	0	3	1
Evadne	0	0	0	0	0	4,420
Podon	2	0	0	0	0	2,380

present, are seen to characterize the Newfoundland rather than the Quebec side. They are not, however, very numerous. However, in the series of tows (stations 22–30) taken between Great Mekattina Island and Ferolle Point, which were largely over Mekattina Bank, *Centropages* and *Temora* were abundant (the latter

very abundant) at all stations except the first, whereas *Anomalocera* was, considering its large size, abundant at a station in the middle. *Evadne* and *Podon* were in abundance close to shore and were absent over the Bank. Here are seen the centres from which these forms are carried in the surface water out through the Strait along its south shore. They are produced in the relatively stationary and shallow water that covers Mekattina Bank and that occupies the bays along the Newfoundland coast between Rich Point and the inner end of the Strait, which is the St. Barbe district.

On the Expedition, the Copepod *Anomalocera* was seen as being a conspicuous indicator of the water issuing from the Gulf through the Strait of Belle Isle, and it sometimes gave the water a distinct blue colour. Since it was not taken in large numbers in the No.5 net, Mrs. Pinhey (1927a) made a special examination of the No.0 surface tows to determine its distribution, and showed the results in figures. It was generally distributed in Cabot Strait and in the centre of the Gulf, as well as off the south coast of Newfoundland, but was absent along the north shore of the Gulf from the Strait to Great Mekattina (Pinhey, 1927a, map III). In the Strait it varied with the presence of pure Gulf water and mixed water. Following the passage outward of Gulf water, it was found along the east coast of Newfoundland from the Strait south to the mouth of White Bay, but no farther.

The penetration of northern (slope) water of high salinity into the region is shown very well by certain planktonic ostracods (Davidson, 1924). They are in deep water and occur at the surface to a very limited extent at night. *Conchoecia elegans* was taken in the deep outer part of the Labrador Current (*Arleux* stations 49 and 52), at deep stations off the east coast of Newfoundland, in Cabot Strait (*Arleux* stations 1 and 2) and at three stations (9, 17 and 60) along the deep Rich Point gully to its very head off Rich Point (Davidson 1924, Fig. II, not Fig. I). It is quite evident that such water enters the Gulf of St. Lawrence only through Cabot Strait. *Conchoecia obtusata* was at the same two stations in the outer part of the Labrador Current as the preceding species and also at the same two in Cabot Strait, but not elsewhere. It shows less tendency to reach relatively shallow water in the penetration shoreward of the slope water. A third species, *Conchoecia borealis*, was not found in the Labrador Current, but was at the deepest station (2) in Cabot Strait. It shows still less tendency to reach relatively shallow water.

THE FISHERIES AND THE FISH

The fisheries reveal the Arctic influence that is exerted by movement of ice-laden water from the north along this coast. The Labrador Current brings in large numbers the Greenland seals, which keep on the fringe of the ice-covered ocean. It does not eliminate salmon and cod, which are to be found along the Labrador coast as far north as Hudson Strait. Herring, however, are definitely more limited in northward distribution, and lobsters are practically nonexistent even in the Strait of Belle Isle, with no fishery there nor any on the outer Newfoundland coast as far south as White Bay.

Detailed data on the fisheries are for the most part unavailable for the coasts of Newfoundland and of Labrador to the inner end of the Strait of Belle Isle. The fisheries statistics, often in much detail, have been published regularly for very many years for the north shore of the Gulf of St. Lawrence, starting at the inner end of the Strait of Belle Isle. That there is a very great contrast between the fisheries of the west coast of Newfoundland and the north or Quebec shore of the Gulf opposite is shown by the quantities of herring and lobsters caught in the year 1911, for which comparative figures are available. The Newfoundland coast had 85,666 barrels of herring and 14,660 cases of lobsters, whereas the Quebec shore from Natashquan to Blanc Sablon had only 2,809 barrels and 917 cases, respectively. The statistics that are available make it possible to learn something of the character of the very poor fishery along the Quebec shore.

Arctic Immigrants

Greenland seals are regularly taken along this north shore inside the Strait of Belle Isle, but their numbers decrease westward. The take of seals for the last 10 years for which published data happen to be available (1937–46 inclusive) was 180 per mile per year next the Strait, 87 in the next district and 32 in the district around Cape Whittle at the inner end of the Esquiman Channel. In the next district, which is north of Anticosti Island, the take dropped to four per mile per year. This sharp reduction on the other side of Cape Whittle is in agreement with the westward limit in distribution of icebergs and Arctic comb jellyfish (*Mertensia*). Also, it agrees with the change in the seal fishery, from the use of nets along shore for taking the seals in the late autumn or early winter when the floating ice appears and in the spring when it disappears, to the use of vessels out of western ports from which the seals are taken on the ice out to sea. Sometimes the main catch in the Gulf was not by the nets along the eastern part of this shore, but by vessels operating from western ports. Now, even one vessel from St. John's or from Halifax will, when operating in the Gulf, almost always take a catch greater than the catch with nets along the whole shore. The great variation that there may be from year to year in the availability of the seals is shown by Table IV.

After being practically absent from the district of Bonne Esperance next the Strait for a number of years, they were abundant in 1876 and 1877. There was a reverse change for the districts of Natashquan and Mingan, although herds of the seals were seen in the St. Lawrence estuary off Pointe des Monts in 1876 and 1877. In 1878, the seals did not come inshore near the Strait, but were in large numbers farther in. Then in 1879 the catch was low everywhere and it was reported, "This year there was but little good ice came in through the straits. In the Bonne Esperance division this fishery failed entirely". In 1880 the situation was somewhat reversed and the report was, "The seals came in late, and the seal-bearing ice passed rapidly through the straits before the easterly winds". The catch was better near the Strait, but the chief increase was far in by the vessels.

Greenland seals and hooded seals are Arctic animals that move south with falling and north with rising temperature, more or less in relation to the ice. They

TABLE IV. Number of seals taken and the number of seal nets operated in 1877, 1878, 1879 and 1880 in the successive districts going westward, the first two covering the coast as far as Cape Whittle.

District	Bonne Esperance	St. Augustine	Romaine	Natashquan	Mingan	Moisie
1877 Seals	3,230	779	163	421	2,971	20
Nets	40	134	21	0	0	0
1878 Seals	605	2,074	906	4,983	11,090	60
Nets	59	99	19	0	0	0
1879 Seals	0	1,422	185	52	830	40
Nets	38	?	10	5	0	0
1880 Seals	570	1,431	137	2,188	20,865	30
Nets	54	40	9	0	(0)	0

are, therefore, winter immigrants into the Gulf, whose movements are rather clearly seen, since they are at the surface of the water. They seem to be the best indicators of the extension of Arctic influence at the surface.

The occurrence of these northern seals in the Esquiman Channel is seasonal, corresponding with the cold part of the year when Arctic conditions extend farthest south. Their distribution is in accordance with transport of ice from the north by the currents, extending as far as the ice does before it melts. Mr. H. D. Fisher, who is investigating the fishery for these seals, informs us that they swim southwestward along the coast and follow the indentations of the shoreline into and around bays, when these are not frozen over, so that they are not merely transported by the currents, like the ice with which they are associated. In this southwestward movement they keep to the northwest shore of the Esquiman Channel, no evidence being available of their occurrence on the warmer southeast or Newfoundland shore. When the ice disappears in the spring, they retreat northeastward and are not seen on either shore of the Esquiman Channel, being doubtless offshore in cooler waters, but they appear in the cold shore water of the north side of the Strait of Belle Isle.

The Greenland cod, *Gadus ogac*, is a shore form. Young, apparently of this species but not certainly distinguishable from *G. callarias*, were commonly taken in the plankton on the north side of the Strait of Belle Isle (*Prince* station 442) and were evidently being carried into the Gulf. Adults were numerous at Chateau Bay on the north side at the outer end, and were readily caught on hand lines from the *Arleux*. They were also seen at Quirpon on the south side, and were reported as regularly found there, but not in large numbers. The "tom-cod" or rockcod, which according to Jeffers (1932) occurred at Raleigh, did not migrate and were considered by the fishermen as a different species from the ordinary cod, were doubtless Greenland cod, as suggested by their dark appearance. Specimens from 10 to 13 centimetres long were obtained for us at Blanc Sablon in 1923.

Vladykov (1945) has stated that several quintals of Greenland cod could be taken each year between Harrington Harbour and Blanc Sablon. Fortin (1866)

described this as a new species, *Morrhua ductor*, or pilot codfish, the latter name being given to it by fishermen because they take it on the banks before the ordinary cod appear. He reported it as occurring not only on the banks but also along shore, but as being a northern form, rare in the Gulf. He obtained specimens off the Watshee-shoo River near Natashquan. It was taken by the Royal Ontario Museum at Godbout in the estuary of the St. Lawrence, from which Vladykov (1945) has reported it. Cornish (1912) evidently obtained it at Tignish, P.E.I., as the pilot-fish, with a similar behaviour to that reported by Fortin. The Royal Ontario Museum has specimens from Miramichi Bay, N.B. (April, 1949), and from the Bras d'Or Lakes in Cape Breton (1948). To what extent it may breed successfully inside the Gulf is quite uncertain. What seemed to be larvae of this species (over 12 mm. long, occurring at *Arleux* Station 45 on the outer Labrador coast on August 18, and at station 57 on the north side, but not at station 55 on the south side at the inner end of the Strait on August 21) were taken at *Arleux* stations 33 and 35 on the north side of the Esquiman Channel just inside the Strait, but not at stations 30 and 32 on the south side. Correspondingly, there were some at stations 22 and 23 on the north shore near Great Mekattina, and at stations 13, 15, 16 and 17 near Cape Whittle, but none near Anticosti and Bay of Islands, Newfoundland. It may be that they breed successfully as far as Cape Whittle, but these larvae may well have been carried from the outer coast of Labrador like other planktonic forms. This species is a sedentary fish that is an immigrant in the larval stage from the Labrador Current.

The polar cod, *Boreogadus saida*, was taken in the deep cold water with the young fish trawl and with the shrimp trawl, first at Mistanoque Bay on the north side of the Esquiman Channel on August 2 and 3, then in Temple Bay inside Chateau Bay on the north side of the Strait on August 13 and 17, and at Bonne Esperance on the north side of the Channel on September 13. A specimen 9.3 cm. long was obtained for us at Blanc Sablon. The larvae were found in the plankton only at *Arleux* stations 33 and 35, on the north side of the Channel just inside the Strait on August 16, six in all from 18 to 22 mm. long. It would appear that they were being brought from the Labrador Current and were populating the deep and ice-cold water, as in the barrier-fjord of Temple Bay, where such water is pocketed and not subjected to warming or mixing with warmer water. That it reaches far into the Gulf to some extent is shown by Vladykov's (1945) report of its being taken in the estuary of the St. Lawrence, where there is very cold water at some depth.

A considerable variety of Arctic forms was found, with distributions similar to those of the two species just considered. The sculpin, *Gymacanthus tricuspis*, which Storer (1857) had reported (as *Acanthocottus patris*) from Red Bay and Great Mekattina was taken with the shrimp trawl in Temple Bay and at Bonne Esperance and by seining at Red Bay, all of which are along the north shore of the Strait and Channel. Vladykov and Tremblay (1935) have reported it from the estuary of the St. Lawrence. The Arctic sculpin (*Icelus bicornis*) was taken in the shrimp trawl in Temple Bay on both August 13 and August 17. The shanny, *Leptoclinus maculatus*, was taken in the deep, ice-cold water of Temple

Bay on August 13 and 17 in the shrimp trawl and the young were taken in plankton off the north shore of the Esquiman Channel at *Arleux* stations 35, 23 and 17. It has been taken in the estuary of the St. Lawrence (Vladykov and Tremblay, 1935) and (Bigelow and Welsh, 1925) as far south as the Gulf of Maine, where it is "to be sought in cold water in the bottom of deep isolated sinks", which correspond with the barrier fjord of Temple Bay. The Blennid *Lumpenus fabricii* was likewise taken repeatedly in Temple Bay and does not seem to have been previously reported so far from the Arctic. Another Blennid, *Stichaeus punctatus*, was seined at Red Bay and Bradore Basin along the north shore and at Old Port-au-Choix near Rich Point, Newfoundland. Its young were taken only near the north shore, at *Arleux* stations 69 and 57 at the two ends of the Strait and at stations 35 and 13 at the two ends of the channel. The only record farther south is for Chedabucto Bay, N.S. (Cornish, 1907). A Liparid, apparently the Arctic *Liparis major*, was taken in the deep, ice-cold water of Temple Bay and also at Red Bay. The young were in the plankton along the north shore of the Strait and the Channel, at *Arleux* stations 69, 23, 17 and 14.

Southern Immigrants

The mackerel, *Scomber scombrus*, is abundant in the southern part of the Gulf. In accordance with this, the eggs and fry were taken in 1923 in the Cape Breton Current, which flows out of the Gulf, but not elsewhere (i.e. near Newfoundland or the northeastern part of the Gulf). At *Arleux* station 1, with a 25-metre-deep layer of warm water near the surface, 34 eggs and 68 fry were taken, the eggs in late stages and mostly at the surface, the small larvae numerous at 25 metres depth and the largest ones at the surface. At *Arleux* station 2, just outside the Current, one large larva was taken at the surface.

Enquiries indicated that scarcely any of these fish were being seen near the Strait, although they were remembered from long before. However, they were stated to be not unusual in traps in June at Brig Bay where the warmest water is, and two had been taken at Quirpon on the south side of the Strait at the outer end. Jeffers (1932) saw several taken from cod traps at Raleigh on the south side of the Strait in late July of 1929. It is to be inferred that they pass up the west coast of Newfoundland, in the warm water, and through the Strait along the south shore.

When the mackerel stocks were very abundant around 1880, they were taken in small quantities on the north shore of the Channel, and the locations of the catches were then given in detail. For 1871, it was officially stated (Lavoie, 1872) that, after being absent from the northern part of the Gulf for forty years, they had returned and that seine hauls of 400 or 500 barrels had been seen at Bonne Esperance and Mekattina, but they dropped off again in the mid–1870's. The details for the years 1877, 1878 and 1879, in which 883 barrels were reported for the north shore of the Channel, show Great Mekattina and Bonne Esperance to have been the centres of two lots of the fish, the former being much the larger. Roughly there were 67 barrels at Harrington, 598 at Great Mekattina, 82 at St. Augustine and 34 at Chicatica. There were only 102 barrels at Bonne Esperance,

from Old Fort Island to Salmon Bay. From these facts, it may be inferred that the mackerel reached the region of Great Mekattina in the circulation of water from Rich Point along the south side of Mekattina Bank, and that they reached Bonne Esperance in the circulation from the south shore to the north shore just inside the Strait.

Haddock are easily recognized, but are too few to be of any account except on the southern part of the west coast of Newfoundland, where they are taken at Codroy in July. They are found all along that coast, a few being reported at Brig Bay and at Flower Cove. Jeffers (1932) obtained one at Raleigh, and a few were reported both at Quirpon and at St. Anthony down the east coast of Newfoundland. They seem to be along the course that the current takes from Cabot Strait. On the north shore, several are said to be taken every year at Chateau Bay, but none at Blanc Sablon or Bradore. About ten were said to have been taken at Bonne Esperance in 1923, and one at Mistanoque. There is limited movement of haddock, therefore, across to the north shore, and chiefly inside the Strait. Pollock are rarer, the only reports being that they are not rare at Bay of Islands and that one was taken at Flower Cove several years ago. This is in accord with their rarity in the Gulf inside Cape Breton Island. The movement shown is north along the west coast of Newfoundland.

Endemic Species

Some of the species that evidently breed successfully in the region seem to show the effects of the water circulation in various ways.

The rosefish, *Sebastes marinus*, was taken only as larvae in the plankton, and in largest numbers between Anticosti Island and Cape Whittle. This corresponds with the adults being in mid-water over considerable depths, and with the distribution found in the Gulf on the Canadian Fisheries Expedition of 1914–15 (Lea, 1919). The larvae were taken in the upper layer of the water, being usually more abundant during sunlight in the surface tow than in the 25-metre tow. In accordance with this, they were found (Table V) over Mekattina Bank and north along the west coast of Newfoundland to the Strait and through it on the south side, being taken at *Arleux* station 64 off Cape Norman. They were absent from the cold water passing along the north shore from the Labrador Current, as at *Arleux* stations 45, 69, 57, 35, 33 and 22. The four-bearded rockling, *Enchelyopus cimbrius*, shows a similar condition, but the numbers of larvae were smaller, and they were more definitely confined to surface water, 142 being in the surface tow and only nine at about 25 metres depth. The eggs were few and were taken over deep water, at stations 1, 2, 9, 10, 16 and 17 and on Mekattina Bank at stations 24 and 25. It has been found by experiment that temperatures as low as 10°C. do not permit successful development of this species. Accordingly, eggs in late stages were restricted to the warm Cape Breton Current, and small larvae (under 10 mm.) were virtually restricted to that Current and to the warm water along the west coast of Newfoundland to and through the Strait. Large larvae (over 10 mm.) were more widely distributed, the largest of all being near Anticosti Island. On the Canadian Fisheries Expedition (Lea, 1919) larvae found in the Gulf

TABLE V. Numbers of larvae of *Sebastes marinus* and (in parentheses) *Enchelyopus cimbrius* taken in the No. 0 metre net at *Arleux* stations in 1923.

Station	1	2	3	6	8	9	10	11	12	13
Kind of Haul										
Vertical	0(2)	1(0)	1(0)	0(0)	1(0)	1(0)	0(0)	4(0)	4(0)	9(0)
ca. 25-m. tow	0(4)	0(0)	2(0)	2(0)	—	31(0)	8(0)	—	206(4)	183(0)
0- to 2-m. tow	0(29)	0(35)	0(14)	—	9(3)	30(5)	10(4)	18(2)	109(2)	27(4)
Station	14	15	16	17	18	19	22	23	24	25
Kind of Haul										
Vertical	0(0)	0(0)	9(9)	3(0)	0(0)	1(0)	—	1(0)	0(0)	1(0)
ca. 25-m. tow	6(0)	5(0)	35(0)	25(0)	6(0)	4(1)	0(0)	12(1)	17(1)	7(0)
0- to 2-m. tow	2(0)	0(1)	1(0)	3(0)	2(2)	7(7)	0(0)	10(3)	1(3)	43(11)
Station	26	30	32	33	35	45	55	57	64	69
Kind of Haul										
Vertical	0(1)	0(0)	0(0)	0(0)	0(0)	0(0)	—	—	—	—
ca. 25-m. tow	2(0)	1(0)	3(1)	0(0)	0(0)	0(0)	—	—	—	0
0- to 2-m. tow	3(3)	20(3)	29(10)	0(0)	0(0)	0(0)	2(0)	0(0)	4(1)	0(0)

were restricted to the shallow southern part with quite warm surface water. The population in the northeastern part of the Gulf may be maintained only by immigration from the south.

The hake, *Urophycis*, known as ling in Newfoundland, is taken by fishermen in southwestern Newfoundland, as observed at Bay of Islands in 1915 and at Codroy in 1923. Our failure to hear of its being taken in the Channel or the Strait may be due to confusion over the name. The young (yearlings) were seined at five places from Cape Rich to Flower Cove in the warm shore water and also at Mistanoque Bay on the north shore. At least the young are distributed through the Channel in accordance with movement of water from their habitat as adults in relation to the deep water of the Rich Point gully.

Capelin, *Mallotus villosus*, were generally distributed, the adults being taken in the seine, young fish trawl, shrimp trawl and even in the metre plankton net. Some were in spawning condition in late August and September on the north side of the Strait. The larvae were widely taken and seemed to reflect by their numbers where they had spawned earliest, being in greatest quantity in the warmest shore water in the Channel and Strait, on the south side. On July 30, 704 were taken at *Prince* station 427 near Rich Point, and on August 16 at *Arleux* stations 30 and 32 near Ferolle Point, 175 and 286, respectively. At *Arleux* stations 45, 69, 55, 35 and 22 in the Labrador Current and along the north shore, the numbers taken in the period from August 15 to September 27 were 0, 5, 0, 16 and 1, respectively.

Cod, *Gadus callarias*, were quite generally distributed, both as adults and as eggs and larvae. Eggs and larvae were absent in the Cape Breton Current. Around Cape Ray, Newfoundland, eggs were numerous and larvae few and small. At the western end of the Channel, the larvae were more numerous than the eggs and some were fairly large. At the eastern end of the Channel, the eggs were

numerous and the larvae small. On the north side of the Strait, eggs were numerous and there were no larvae. This reflects later spawning in the colder water.

The young (yearlings) were abundant, as seen around the wharves or seined along shore, in the warm water on the south side from Cape Rich to Flower Cove and at Cook's Harbour near Cape Norman. Larger fish are also in shallow water in this region, as taken in traps by the fishermen and as seined by us.

The cod fishery on the north shore is very uncertain. In 1923, it was the best for many years generally along the Newfoundland coast from Codroy to Quirpon. At Cook's Harbour on August 21, the fishing had to stop because the salt for curing was exhausted. From Cape Norman to Quirpon, one dealer stocked 30,000 quintals, more than ever before. Yet across the Strait, from Chateau Bay to Blanc Sablon, the fishery was a failure, and at the latter place it was said to have been the worst in forty years. This was associated with cold water from the Labrador Current. When the warm water from the northwest coast of Newfoundland started to go through the Strait on the south side, the line fishing at Blanc Sablon began to improve, and was satisfactory for the first time on August 21. Also, cod were caught in traps as late as August 27, a new experience. But at Bradore, just inside the Strait on the north side, the cod appeared at the end of July and stayed until the end of August, later than previously known. Also, young cod were abundant around the wharves on September 9. At Flower Cove, just across the Channel, the cod arrive late in June and last about three weeks. After that they are not to be caught in the traps inshore, but only out in deep water. It seems clear that the large cod are in the warm water along the south shore of the Channel and Strait only early in the summer, before it becomes too warm. Movement of this water across the inner end of the Strait gives fish to the north shore of the Channel. But for the north shore of the Strait to get any quantity of cod there must be a strong movement of this water out through the Strait to ameliorate the action of the Labrador Current. At Red Bay, in the centre of the Strait on the north side, the fishery is most uncertain, and seems to depend upon southwest winds, which carry the warm water through. The fish do not stay, the fishing lasting only a few days, but they may return. The westerly winds do away with the fishing at Flower Cove, since they bring too warm water. Also, there the icebergs do not mean poor fishing as on the north shore. Often the best fishing is right beside them, presumably because they prevent the water getting too warm.

The fishery along the north shore of the channel seems to depend upon the fish reaching it from the Newfoundland coast, where the young are in great abundance and where the older fish are in shallow water early in the season. The data indicate that they cross at two points, just inside the Strait and along the south side of Mekattina Bank. The details published for the 1870's make this clear, as summarized for successive districts from east to west in Table VI. As shown by success as well as take, the fish are most abundant at Bonne Esperance district (2) for the crossing inside the Strait and at Great Mekattina district (8) for the crossing south of the Bank, but this varies from year to year. The

TABLE VI. Take of cod (quintals) and success (quintals per fisherman) in districts from Blanc Sablon to Cape Whittle. Numbers represent districts as follows: 1—Long Point to Bradore; 2—Belles Amours to Salmon Bay; 3—Stick Point to Old Fort Island; 4—Dog Island to Chicatica; 5—Mustingue to St. Augustine; 6—River Island to Fonderie à Fecteau; 7—Salt Lake to Pointe Rouge; 8—Great Mekattina to Harrington; 9—Etamamu to Cape Whittle.

District	1	2	3	4	5	6	7	8	9
1875									
Take	410	2,440	2,150	84	2	0	50	760	0
Success	20	43	54	5	0.6	0	5	11	0
1876									
Take	1,300	4,155	2,470	74	12	0	178	1,646	60
Success	59	57	54	7	6	0	13	24	9
1877									
Take	330	6,045	4,250	420	118	101	315	1,185	52
Success	14	81	97	23	7	8	19	18	6
1878									
Take	1,355	6,780	3,600	359	71	0	188	1,952	75
Success	48	75	72	16	5	0	12	31	6

movement of the cod, as carried in the water circulation, determines where it is worth while for fishing to be carried on, and the differences are very great. What happens over the Mekattina Bank where it joints the Newfoundland shore north of Cape Rich must have a very great influence on the fishery on the north shore of the Channel. In 1923, the Bank was covered with water much too cold for cod, and the surface water was evidently somewhat unfavourably warm. The north shore has water of intermediate temperature in summer, but doubtless of too low a temperature in winter.

In the Gulf of St. Lawrence, lobsters are in great abundance in the warm waters of the southern Magdalen Shallows. In Newfoundland waters they are least abundant and of greatest average size on the east coast, along which the Labrador Current passes. For the 10-year period from 1909 to 1918 inclusive, for which data have been published, the average number of cases of lobsters packed per year was 2,197 for the 360 miles of the east coast, 5,844 for the 300 miles of the south coast and 7,953 for the 330 miles of the west coast. The west coast is divided into two districts of about equal extent. The southern district had 3,405 cases per year, whereas the northern had 4,550. Also the northern had smaller lobsters, 259 to a case *vs.* 216, from 1909 to 1914 inclusive. This is in accordance with the warm inshore water in this northern part. This northern part of the west coast, which adjoins the inner end of the Strait of Belle Isle, has the greatest abundance of lobsters.

The north or Quebec coast of the Esquiman Channel, of approximately the same length as and opposite this west coast, offers a great contrast to the latter. Lobsters are comparatively few and the stock rapidly declines with intensive fishing. From 1938 to 1941 inclusive no catch whatever was reported. From 1942 to 1946 inclusive there was an average pack of 233 cases, and the number declined from 498 to 66. The canneries cannot operate steadily and some are

movable. Early in the century, the attempt to develop the lobster fishery was greater. From 1909 to 1918, the average pack was 617 cases, which is to be compared with the 7,953 of the Newfoundland coast opposite. The detailed distribution of the pack shows that it was in greatest amount in the Mekattina region, opposite the main concentration for the Newfoundland coast, and that quantities dropped off rapidly to the eastward, but much less rapidly to the westward. The facts are consistent with the conception that the lobster pack of this north shore of the Gulf is dependent upon immigration from the Newfoundland coast mainly along the course of the circulation of the water westward on the south side of Mekattina Bank to Mekattina and thence along the north shore. There is a very abrupt ending to the good lobster fishing on the west coast of Newfoundland as the Strait of Belle Isle is approached; it is stated that one man packed only part of a case at Flower Cove in 1923; but a few large ones are reputedly found through the Strait and down the east coast of Newfoundland.

The cunner, *Tautogolabrus adspersus*, shows a situation rather similar to that of the lobster. This fish lives in the warm waters of our coast, being abundant and breeding in St. Mary Bay, N.S., at the mouth of the Bay of Fundy, but not breeding successfully in the Bay of Fundy and occurring inside its mouth a short distance only as rare and large individuals. Cunners were seined in the summer of 1923 along the northern part of the west coast of Newfoundland at Port-au-Choix, Brig Bay and Old Ferolle Harbour, and were said to be common in this district where lobsters are plentiful, yet at Flower Cove, at the inner end of the Strait, they were reputedly quite rare. They were reported as unknown at Blanc Sablon, Chateau Bay and Quirpon in the Strait. At Mistanoque Bay, on the north shore of the Esquiman Channel, they were said to be few in number and large.

In the plankton tows, eggs well advanced in development were in large numbers in the surface water in the Cape Breton Current, and larvae were very abundant at a depth of about 25 metres at *Arleux* station 1 and there was one at station 2 on the edge of the Current. On the Newfoundland side, at station 32, there were no larvae, and the very numerous eggs were all in early stages. Only a few of these eggs were taken off Cape St. George at station 6, and none at all across to Anticosti Island, north to Cape Whittle and back to the Newfoundland shore at Bay of Islands. Near the Strait, they were abundant at Ferolle Point, but none were found at Greenly Island. At *Arleux* stations 22 and 23 near Mekattina there were no cunner eggs. At *Prince* station 427 near Ferolle Point in the warm water of the St. Barbe district, there were very many eggs on July 30, and at the neighbouring *Arleux* station 30 on August 16 there were again very many, and two larvae were taken, as if the water were only beginning to be warm enough for the eggs to hatch and the larvae to survive. On the Mekattina Bank, at stations 24, 25 and 26, there were eggs in middle stages, and many of them at station 25. They were evidently being carried from the Newfoundland shore across to the Quebec shore along the south side of the Bank, but the water was not yet sufficiently warm for them to survive. Seeding of the north shore with young may occur only rarely and to a very slight extent. On August 21 at station 55 a few

eggs were being carried out through the Strait on the south side, and at station 64 near Cape Norman on September 6 one larva was taken. It would appear that none survive along this course.

The herring, which is taken in large quantities in winter in the Bay of Islands and in Bonne Bay on the southern part of the west coast of Newfoundland, is not abundant on the north shore of the Channel. From the distribution of the catches it may be inferred that, like the cod, it is carried across the Channel, being in greatest quantity at Bradore and at Great Mekattina. Successive districts in order from Blanc Sablon to Cape Whittle (Table VI), showed the following numbers of barrels as taken in 13 years from 1875 to 1889 (except 1881 and 1883): 1,700; 750; 350; 508; 6; 53; 591; 5,450; 97. There was very great variability: In 1884 there were none anywhere, corresponding to a failure in the Newfoundland fishery. In 1875, 1878 and 1879, they were only in the Mekattina region, and in 1882 and 1888 only in the Bradore region. From the information received in 1923, they are plentiful in the warm water of the St. Barbe district, where they spawn in the spring. In accordance with this the larvae were taken in greatest numbers (21) at *Arleux* station 30 near Ferolle Point, with the numbers decreasing going over Mekattina Bank (ten at 26, four at 25 and none at 24) and going north across the Channel (five at 32, two at 33 and none at 35). To the south and west, very few were taken: three at station 15 near Cape Whittle, one at station 8 near Cape St. George, nine at station 3 off Port-aux-Basques, and one at station 1 in the Cape Breton Current. The sizes of the larvae were not very different, but the single larva in the Cape Breton Current was 25 mm. long, equal to the largest in the St. Barbe district, and only at station 30 were there any under 10 mm. in length, which doubtless reflects later spawning there.

The young herring of 10–15 cm. in length are not infrequently seen at Flower Cove and sometimes at Bradore, at Bonne Esperance and even at Red Bay and Chateau Bay, although not reported for Raleigh (Jeffers, 1932) or at Quirpon on the south shore of the Strait at the outer end. The large fish reach Raleigh, Quirpon and Bonne Esperance in August. We took them in gill nets in August of 1923 at St. Barbe, Mistanoque, Red Bay, Pitts Harbour and Chateau Bay. It may be inferred that the herring of the region are largely produced in the warm water of the St. Barbe district, from which they are carried to the Mekattina and Bradore regions and also out through the Strait.

The fisheries of the north shore of the Esquiman Channel depend upon locally produced fish only in the case of salmon and trout which spawn in the rivers and are related in abundance to the rivers, salmon giving a valuable fishery. Cod are carried from the Newfoundland coast to the Bonne Esperance and Great Mekattina districts, chiefly the former; they do not spread very far and are rather uncertain, but give another valuable fishery. Seals move with the edge of the ice floes, coming from the north in the Labrador Current and reaching the Channel through the Strait along the north shore, and give a rather valuable fishery.

Mackerel in occasional years reach the north shore from the south, along

the west coast of Newfoundland, from which they cross to the Mekattina and Bonne Esperance districts, chiefly the former in accordance with their southern origin. Finally, lobsters are doubtless carried in the larval stage from the populous St. Barbe district of Newfoundland along the south side of Mekattina Bank to the great Mekattina region, whence they spread chiefly westward. These immigrant lobsters are soon fished out.

SUMMARY

1. The earlier knowledge of the Strait of Belle Isle is summarized and the general tidal features are described.
2. A minimum depth of approximately 100 metres and a minimum width of nine miles (14 km.) are limiting factors in the movement of water through the Strait of Belle Isle.
3. Water movements in the Strait of Belle Isle, on the basis of temperature, salinity and density distributions, have been illustrated, involving at times:
   (*a*) a progressive inward movement of water of Arctic and sub-Arctic origin on the north side,
   (*b*) a progressive outward movement of Gulf water on the south side, and
   (*c*) a dominant outward flow of Gulf water.
4. While a dominant flow of water into the Gulf was not observed throughout the short period of observation, the conditions observed on August 16 indicated that there had been a predominant movement westward earlier.
5. The structure of the water columns in the Strait of Belle Isle undergoes considerable change with time, the time differences between maximum temperatures and salinities suggesting that this is related directly to tidal influences.
6. At times some extreme temperature gradients between the waters of the north and south sides of the Strait were observed as follows:
   (*a*) On August 17, in Section V (Figure 6), the surface temperature gradient was from 3.9°C. on the north to 8.1°C. on the south.
   (*b*) On September 6–7, when the dominant flow was outward from the Gulf, the surface temperature gradient was from 4.0°C. on the north to 10.0°C. on the south, and the gradient on the bottom was from less than 0.0°C. on the north to −1.0°C. at the centre of the Strait and 10.0°C. on the south.
7. Three main water masses are found in various proportions in and adjacent to the Strait of Belle Isle as follows:
   (*a*) water with temperature and salinity characteristics of 11°C. and 30.5‰, respectively.
   (*b*) water with temperature and salinity characteristics of −1.6°C. and 33.3‰ respectively, and
   (*c*) water with temperature and salinity characteristics of 3.5°C. and 34.5‰, respectively.
8. In addition other water masses whose characteristics have been in part influenced by land drainage and seasonal warming are found in traces within the area covered.

9. The results of current measurements in the Strait of Belle Isle over a 72-hour period may be summarized as follows:
   (*a*) On the north side of the Strait, the westerly currents were much stronger than the easterly currents. Over a double tidal period there was a residual westerly trend of nine miles (16.7 km.) per day.
   (*b*) On the south side of the Strait, the easterly currents were much stronger than the westerly currents. Over a double tidal period there was a residual easterly trend of eight miles (14.8 km.) per day.
10. The results obtained from the use of drift bottles are in harmony with the double movement through the Strait.
11. The general knowledge of the water movements in the Esquiman Channel, in relation to those of Belle Isle Strait, is summarized. The northeastern part of the Gulf of St. Lawrence may be considered to consist of two large eddies, circulating contraclockwise, one south and the other north of the Mekattina Bank.
12. Horizontal distributions of temperature and salinity in the Esquiman Channel clearly indicate the indraught and spreading of waters through Cabot Strait and the Strait of Belle Isle.
13. Vertical distributions of temperature, salinity and density in the Esquiman Channel and Cabot Strait clearly indicate:
   (*a*) a strong inward movement through Cabot Strait on the Newfoundland side, and a strong outward one on the Cape Breton side,
   (*b*) a strong northeasterly movement along the west coast of Newfoundland, and
   (*c*) a somewhat weaker westerly movement along the Mekattina shore and entering Jacques Cartier Passage.
14. Arctic waters in the Esquiman Channel were composed at the time of the survey of:
   (*a*) those which have entered through the Strait of Belle Isle, and
   (*b*) those which have entered through Cabot Strait.
15. Planktonic animals were used as indicators of the principal kinds of water related to the Strait.
16. The Ctenophore *Mertensia ovum* and the Copepod *Acartia spiniremis* are characteristic of the Labrador Current and extend their distribution thence along the north side of the Strait and of the Esquiman Channel as far as the icebergs go, that is, to the vicinity of Cape Whittle and Anticosti Island. They are absent from the warm water along the south shore.
17. The Amphipods *Themisto libellula* and *Pseudalibrotus glacialis* are similarly indicative of water from the Labrador Current, but are largely or wholly eliminated by September, through rising when active by day into the surface water, which becomes too warm for them.
18. The Appendicularian *Oikopleura vanhöffeni* also is indicative of water from the Labrador Current and begins to degenerate when this is mixed in the Strait with warmer water, but remains partially alive during more extended transport into the Gulf than obtains for the preceding forms.
19. Three Copepods, *Centropages hamatus*, *Temora longicornis* and *Anomalo-*

cera patersoni, and two Cladocera, *Evadne nordmanni* and *Podon leuckarti*, are characteristic of the warm, shallow water over the Mekattina Bank near the northern part of the west coast of Newfoundland. They are indicators for this water which at times moves out through the Strait along the south shore, partly flooding toward the north shore, and down the east coast of Newfoundland.

20. Three species of Ostracods of the genus *Conchoecia* are characteristic of the deep, northern water of high salinity along the slope of the continent. They indicate to different degrees the penetration of some of this water into the Gulf through Cabot Strait and northward along the west coast of Newfoundland almost to Cape Rich.
21. The fisheries of the Strait and of the Esquiman Channel are seen to reflect the distribution of the three principal kinds of water.
22. Greenland seals are regularly taken with set nets along the north shore of the Esquiman Channel, but not on the Newfoundland coast opposite. They are fished in the Gulf beyond Cape Whittle only out from shore. They migrate seasonally from and to the Arctic and represent the Arctic conditions that develop in winter.
23. The cod and the herring are generally distributed, but their fisheries are definitely related to the west coast of Newfoundland and to passage of water from this coast through the Strait on the south side and across to the north shore of the Channel along the south side of Mekattina Bank and at the inner end of the Strait.
24. The mackerel represent warmer water and only occasionally reach the region from the south, taking the same courses as do herring and cod to reach the north shore.
25. Lobsters are most abundant in the warm shallow water of the northern part of the west coast of Newfoundland. A certain number reach the north shore at Mekattina, evidently through transport along the south side of the Bank, and mainly westward thence.
26. Hake, which are characteristic of the deeper water, are fished in its extension northward from Cabot Strait along the west coast of Newfoundland.
27. Certain Arctic fishes, *Gadus ogac, Boregadus saida, Gymnocanthus tricuspis, Icelus bicornis, Leptoclinus maculatus, Lumpenus fabricii, Stichaeus punctatus* and *Liparis major*, were found along the north shore of the Strait and the Esquiman Channel and thus reflect the course of water from the Labrador Current.
28. Larvae of *Sebastes marinus* and *Enchelyopus cimbrius*, fishes related to deep water, were found mainly in the water of the deep gully south of the Mekattina Bank. Thence they were evidently being carried as surface forms both over the Bank and to and through the Strait on the south side.
29. The cunner, *Tautogolabrus adspersus*, which fails to breed successfully in the cool waters of the Bay of Fundy, was found to be abundant with the lobsters in the warm shallow water along the northern part of the west coast of Newfoundland. A few reach the north shore of the Channel, but there is no indication that any survive when carried into and through the Strait.

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Adaptation of the "Drop Plate" Method for the Enumeration of Red Halophilic Bacteria[1]

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ABSTRACT

The quantitative determination of total numbers of red halophilic bacteria in contaminated solar salts and discoloured salt fish has been made possible through the successful adaptation of the "drop plate" method. The maximum number of colonies is reached after eight days for pure strains of *Ps. salinaria*, and after 14 days for the red halophiles present in contaminated solar salts. A brief statistical study has shown that a fair degree of reliability can be obtained with the method. From series of counts, the total error expressed as coefficient of variation is shown to vary from 3.34 to 8.72 per cent. Good reproducibility is also obtained when random samples are taken from stocks of contaminated salt.

INTRODUCTION

Many aspects of the work on red halophilic bacteria present in salted fish and contaminated salt have not been adequately investigated owing to the lack of an appropriate method for obtaining an accurate quantitative determination of the total numbers. Because of inherent difficulties, the conventional methods for counting bacteria cannot be applied to the red halophiles. The direct microscopical counting method exhibits, to a greater degree, the limitations already noted by various workers in other fields. It does not differentiate viable from dead cells or chromogenic from nonchromogenic organisms. The ordinary "pour plate" method is also definitely impractical, since the red halophiles are strict aerobes growing only at the surface of nutrient media. Recently Castell (personal communication) has suggested a "dilution count", but he noted that approximate numbers rather than absolute numbers were obtained. Consequently, most studies have been limited to the determination of the presence or absence of red halophilic bacteria; the accuracy of increases or decreases in total numbers could not be properly evaluated.

The present work deals with the application of the "drop plate" method as described by Reed and Reed (1948), to the enumeration of red halophilic bacteria from contaminated salt and discoloured salt fish. Comparing the "drop plate" with the "pour plate" method with pure cultures of non-halophiles, these workers have shown that the former method gave higher numbers and smaller standard error from a series of counts. More recently, Pomales-Lebron and Fernandez (1952) have proposed a "drop surface plate" method for estimating the number of viable bacteria in tissues and broth cultures. By comparing with the conventional pour plate technique, they concluded that it was less liable to errors in counting. The present plating procedure consists simply in adding, with a calibrated dropping pipette, drops of serially diluted suspensions of bacteria on to the surface of an appropriate agar medium. After proper incubation time,

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the bacteria present in each drop of suspension will develop into well-spaced surface colonies that can be rapidly and accurately counted.

EXPERIMENTAL METHODS

CALIBRATION OF PIPETTES. The dropping pipettes are made in the laboratory, as described by Donald (1915), by drawing 7-mm. glass tubing to form long gradual tapers. The tips are then cut uniformly and at right angles to the axis of the pipettes, to measure 0.047 inches in outside diameter. As indicated by Reed and Reed, a steel plate ⅛ inch thick with one hole 0.047 inch in diameter is found very convenient for gauging pipette tips. When the pipettes are held in a perpendicular position and a flow rate of 25 to 30 drops per minute is allowed, they will deliver approximately 40 drops of water per ml.

For brine solutions used as diluent, the pipettes may be accurately calibrated by weighing a large counted number of drops of such brines on a precision balance. Then the density of the brine solution is determined. The number of drops per ml. is obtained by working out the following equation:

$$\text{No. of drops per ml.} = \frac{N \times D}{M},$$

where N = total number of drops; M = total mass of drops; and D = density of brine solution.

CULTURE MEDIUM AND INOCULA. The medium employed throughout the experimental work is an improved skim milk–salt agar whose composition and preparation have been described in a previous paper (Dussault and Lachance, 1952). The pH of the medium is adjusted at 7.5. The inocula consist of contaminated Cadiz and Turk's Island salts and six-day-old cultures of *Ps. salinaria* Harrison and Kennedy: strain No. 1, isolated from Cadiz salt and strain No. 8 isolated from reddened salt cod. *Sar. littoralis*, also a common contaminant of solar salt, has not been included in the present study. However, experiments have shown (unpublished data) that this genus can equally well be submitted to a quantitative analysis using the described counting method and the same culture medium.

DILUTION. For the counting of red halophilic bacteria in contaminated commercial salt, a ten-gram sample is weighed and diluted with sufficient 10 per cent brine (10 g. NaCl in 100 ml. distilled water) to make 100 ml. This original dilution, representing 1:10, is further diluted serially with 20 per cent brine (20 g. NaCl in 100 ml. distilled water). Since most satisfactory counts are obtained when each drop of dilution contains from 20 to 40 colonies, dilutions have to be prepared accordingly. With most commercial salts, whose contamination is unknown, dilutions 1:100, 1:500, 1:1,000, and 1:5,000 will ordinarily yield counts within the proper range. For pure cultures of red halophiles, a light suspension is prepared and diluted with 20 per cent brine. However, the range of dilution will be determined by making a rough estimate of the concentration of bacteria present in the original suspension.

PLATING. Freshly poured and cooled plates containing 20 ml. of skim milk–

salt agar are incubated at 37°C., with lids partially off, for approximately 30 minutes, in order to dry off surface droplets of water. Then, with calibrated dropping pipettes, drops of the selected dilutions are added, usually six drops to a plate. It is essential that pipettes be held firmly, slightly above the surface of the medium, so that drops fall freely after having reached their maximum and uniform size. Also the drops should be evenly spaced so that they neither run into each other nor reach the edge of the plate. A few minutes after the drops have been delivered, the plates are gently rotated so as to spread the area of the drops from 10 mm. in diameter to approximately 25–30 mm. When the drops have been absorbed by the agar, the plates are inverted and placed in the incubator at 37°C.

COUNTING. After the proper incubation time, individual colonies are easily spotted by their red color against the white background of the medium and are conveniently counted with the aid of a hand lens under good lighting. The total number of bacteria per ml. or per g. of the original material is finally calculated by multiplying the number of colonies per drop, by the number of drops per ml., by the dilution factor.

EXPERIMENTAL RESULTS

TIME OF INCUBATION FOR MAXIMUM COUNT. The incubation time required to yield a maximum colony count was first investigated. For this purpose, series of 10 replicate plates were inoculated with suspensions of the two salts and of the two *Ps. salinaria* strains according to the described procedure. The plates were then incubated at 37°C. However, it was found necessary to keep a dish of water in the incubator in order to retard excessive desiccation of the culture medium and crystallization of the incorporated NaCl. With all four inocula, the first colonies began to appear on the fifth day of incubation but too faintly to be counted completely. Thereafter total counts were made on each successive day. The average of replicate plates, plotted in Figure 1, shows that, for both *Ps. salinaria* strains, the maximum count is obtained on the eighth day, whereas, for the two commercial salts, an incubation period of 14 days is required.

RELIABILITY OF METHOD. The true accuracy of the proposed method cannot be evaluated because there is no standard method with which it can be compared. However, from a number of determinations made with the two contaminated salts and the two *Ps. salinaria* strains, a fair idea of the reliability of the method has been gathered. A brief statistical analysis of such counts has been made including standard errors and coefficients of variation. Each datum in Table I represents the total count of bacteria obtained from the average of six drops in one plate. For the samples of commercial salt the total counts represent the actual number of bacteria per gram of salt while for the two strains of *Ps. salinaria*, they merely represent the concentration of organisms per ml. of the original suspension. It is shown that for the six series of total counts, the standard errors of each mean vary from .049 to .095 $\times$ 10^6 and the coefficients of variation from 3.34 to 8.72 per cent.

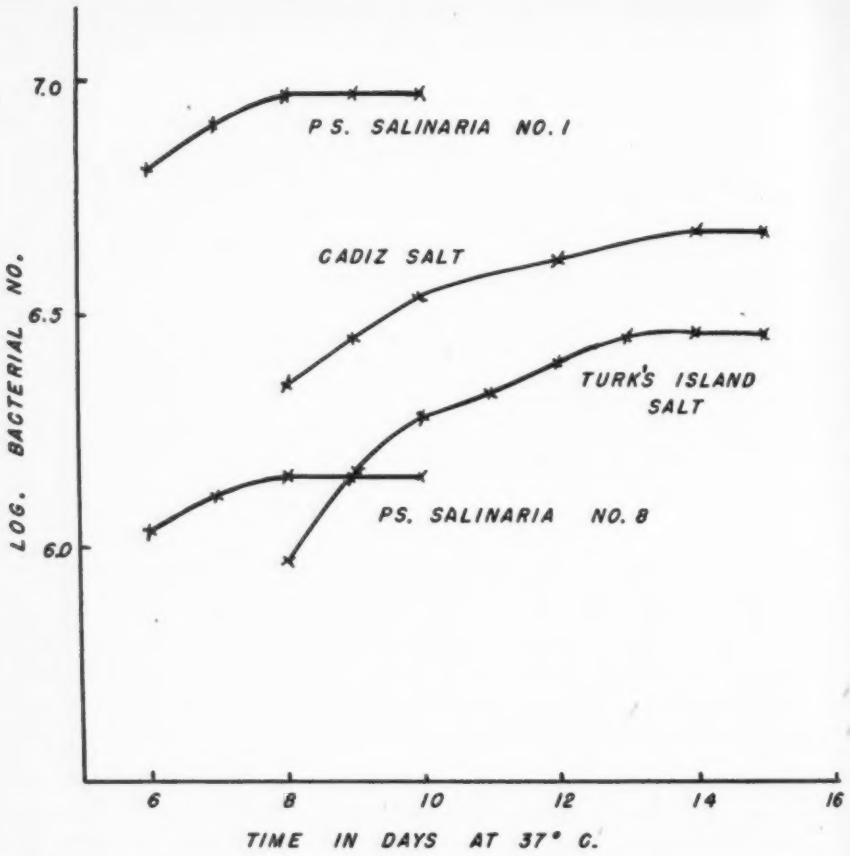

FIGURE 1. Time of incubation at 37°C. for obtaining maximum count of red halophiles from solar salts and strains of *Ps. salinaria*.

REPRODUCIBILITY OF RESULTS. For the purpose of determining if a representative total count can be obtained by taking one sample only from a stock of contaminated salt under analysis, a reproducibility experiment was performed. Five 10=g. samples were chosen at random from the same lot of Cadiz salt and serially diluted as previously described. With the calibrated pipette, six drops of the appropriate dilutions of each sample were added to five replicate plates of skim milk–salt agar. The total counts calculated after the proper incubation time at 37°C. are shown in Table II. The mean values obtained for the five samples vary from 3.18 to 3.33 $\times$ 10^6, the standard errors of each mean, from .032 to .10 $\times$ 10^6, and the coefficients of variation from 2.2 to 7.0 per cent. It is therefore evident that the total counts obtained from the five samples agree quite closely and that, unless extreme clumping of organisms occurs, it is safe to assume that a single sample should give a representative estimate of the red halophiles present in a stock of contaminated salt.

TABLE I. Drop plating of red halophilic bacteria from contaminated solar salts and of strains of *Pseudomonas salinaria* on skim milk–salt agar at 37°C. Counts $\times 10^6$.

Plate no.	Turk's Island salt		Cadiz salt		*Ps. salinaria*	
	Sample 1	Sample 2	Sample 1	Sample 2	Strain No. 1	Strain No. 8
1	2.80	2.50	3.98	4.13	4.27	7.94
2	2.84	2.35	3.68	3.94	4.14	7.34
3	2.77	2.50	3.64	4.36	3.80	7.54
4	2.73	2.84	3.71	4.13	3.94	7.41
5	2.92	2.54	3.64	4.09	4.47	7.14
6	2.62	2.39	3.33	4.17	4.20	7.41
7	2.69	3.07	3.26	4.44	4.80	7.14
8	3.07	2.65	3.75	4.47	4.40	7.74
9	2.58	2.39	3.79	4.19	4.47	7.60
10			3.86			
Mean	2.77	2.58	3.66	4.22	4.28	7.47
Standard error	0.049	0.075	0.066	0.055	0.095	0.083
Coeff. of variation	5.25	8.72	5.73	3.91	6.66	3.34

DISCUSSION

The complete absence of any other method for the accurate enumeration of the total number of red halophilic bacteria in commercial salt and salted fish emphasizes the merits of the one presently described. For the same reason its true accuracy cannot be definitely evaluated. But since the coefficient of variation is generally considered to be independent of the original culture, of the dilution used, and of the mean count, the experimental results presented in this study are compared with those of other workers on that basis.

It is generally accepted that the total error of any plate count is chiefly made up of two rather distinct sources of deviations: (*a*) the dilution error due to the

TABLE II. Drop plating of red halophilic bacteria from random samples of contaminated Cadiz salt on skim milk–salt agar at 37°C. Counts $\times 10^6$.

Plate no.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	3.26	3.15	3.26	3.49	3.26
2	2.96	2.92	3.18	3.07	3.22
3	3.33	2.96	3.15	2.96	3.15
4	3.41	3.49	3.37	3.49	3.26
5	2.99	3.37	3.71	3.22	3.37
Mean	3.19	3.18	3.33	3.25	3.25
Standard error	0.08	0.10	0.09	0.097	0.032
Coeff. of variation	5.6%	7.0%	6.0%	6.6%	2.2%

Mean count, all plates (25), 3.24×10^6; standard error, 0.039×10^6; coefficient of variation, 6.02%.

pipetting of aliquots, and (*b*) the distribution error, which is the variation in number of colonies, due to sampling, between replicate plates of the given dilution. In an extended study, Snyder (1947) has found the former to be equal to 2.0 per cent with calibrated capillary pipettes, and the latter, to vary between 7.3 and 8.9 per cent. He therefore concluded that no significant contribution to the total error can be expected from the use of such pipettes. In a similar study, Jennison (1937) evaluated the distribution error of plate counts and stated that, under good experimental conditions, the coefficient of variation will average 4–5 per cent. Testing the drop plate method with *Salmonella typhimurium*, Reed and Reed (1948) reported the results obtained by six operators having varying degrees of experience with the drop count procedure. The coefficients of variation ranged between 3.4 and 7.0 per cent.

In the light of these results, it is felt that the drop plating method can be advantageously applied to the counting of red halophiles found in contaminated salt and salted fish. The total errors calculated from the experimental counts reported in the present study, expressed as coefficient of variation, indicate that a fair degree of accuracy and reliability can be obtained. It is further shown that fairly good reproducibility can also be obtained by taking random samples from a stock of contaminated salt. The only disadvantage, so far, is the long incubation period required for obtaining the maximum counts of red halophiles in solar salt samples. From one particular Cadiz salt sample, seven different strains of red halophilic bacteria were isolated according to such characteristics as size of colony, surface appearance, intensity of pigmentation and rapidity of growth. It seems that the presence of some slow-growing, light-pigmented strains accounts for the fact that a minimum incubation time of 14 days is required in order to obtain a complete total count. However, it is hoped that, with the use of the adapted drop plating method, this difficulty, along with many other problems dealing with the cultural characteristics of red halophiles, will be successfully investigated.

SUMMARY

The "drop plate" method for counting viable bacteria has been adapted to the red halophiles found in contaminated salt and discoloured salt cod. The total counts obtained experimentally show fair reliability and good reproducibility from random sampling. However, one disadvantage is the long incubation period required for obtaining complete total counts from samples of contaminated solar salts.

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List of the Parasites Recorded from Sea Mammals Caught off the West Coast of North America[1]

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ABSTRACT

A parasite-host list and host-parasite list, with complete references, of the ecto- and endoparasites recorded from marine mammals of the North American west coast are presented. One trematode, 7 nematodes, 1 acanthocephalid, 1 copepod, 6 cirripedes, 5 amphipods and a lamprey are reported from 12 species of Cetacea. From 8 species of Pinnipedia, 5 trematodes, 4 cestodes, 12 nematodes, 7 acanthocephalids, 5 Acarina and 4 Anoplura are listed. A single species of Fissipedia has yielded 4 trematodes, 1 cestode, 1 nematode and 2 acanthocephalids, almost all of which have been found in Pinnipedia.

INTRODUCTION

During the course of study of a collection of parasites from some sea mammals caught in the coastal waters of British Columbia, it was found necessary to consult a large number of publications dealing with marine mammal parasites. The literature on parasites of this group of animals from the North American west coast was noted to be rather sparse and distributed in a wide variety of journals. It was thus deemed worth while, to facilitate future work, to gather together this knowledge and publish a list, with references, of the known parasites of Cetacea and Pinnipedia caught in the coastal waters of North America between Bering Straits and Lower California.

Several species of parasites reported from California and Stellar sea lions which had died in zoological parks in New York, Washington, D.C., New Orleans, La., California, and Germany are included in the list, as evidence suggests that in most cases they were definitely infected prior to their capture. The California sea lion is restricted in its distribution to California and Mexican waters, while the Steller sea lion is found on both the Asiatic and North American Pacific coasts. Nearly all the records from captive Stellar sea lions indicate that the animals originated on the California coast. The origin of the Steller sea lions from which *Anisakis similis* and *A. tridentatus* were reported was not mentioned. These sea lions died in the Zoological Park of Basel, Switzerland.

The list has been compiled from the literature up to July 15, 1953.

PARASITE-HOST LIST

TREMATODA

Zalophotrema hepaticum Stunkard and Alvey, 1929
Host: *Zalophus californianus*—California sea lion.
Location: Liver.
Localities: New York Aquarium; National Zoological Park, Washington, D.C.
Recorded by: Stunkard and Alvey (1929, 1930); Price (1932).

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Orthosplanchnus fraterculus Odhner, 1905

HOSTS: *Enhydra lutris*–sea otter; *Erignathus barbatus*–bearded seal.
LOCATION: Liver (bile ducts).
LOCALITIES: Aleutian Islands and St. Lawrence Island, Alaska.
RECORDED BY: Rausch and Locker (1951); Rausch (1953).

Hadwenius seymouri Price, 1932

SYN.: *Odhneriella seymouri* (Price, 1932) Skrjabin, 1944.
HOST: *Delphinapterus leucas*–white whale.
LOCATION: Intestine.
LOCALITY: Golovin, Alaska.
RECORDED BY: Price (1932).
REMARKS: Skrjabin (1944) considered *Hadwenius* as a synonym of *Odhneriella*. Yamaguti (1951) retained *Hadwenius* as a valid genus and described a second species.

Phocitrema fusiforme Goto and Ozaki, 1930

HOSTS: *Enhydra lutris*–sea otter; *Phoca vitulina richardi*–harbour seal.
LOCATION: Intestine.
LOCALITIES: Aleutian Islands and St. Lawrence Island, Alaska.
RECORDED BY: Rausch and Locker (1951); Rausch (1953).

Microphallus pirum (Afanasev, 1941) Rausch, 1953

SYN.: *Microphallus enhydrae* Rausch and Locker, 1951.
HOST: *Enhydra lutris*–sea otter.
LOCATION: Intestine.
LOCALITY: Aleutian Islands, Alaska.
RECORDED BY: Rausch and Locker (1951); Rausch (1953).

Pricetrema zalophi (Price, 1932) Ciurea, 1933

SYN.: *Apophallus zalophi* Price, 1932.
HOSTS: *Enhydra lutris*–sea otter; *Zalophus californianus*–California sea lion.
LOCATION: Intestine.
LOCALITIES: Aleutian Islands, Alaska; National Zoological Park, Washington, D.C.
RECORDED BY: Rausch and Locker (1951); Price (1932); Rausch (1953).
REMARKS: Ciurea (1933) created the new genus *Pricetrema* for *Apophallus zalophi* Price, 1932, described from the sea lion.

Stephanoprora denticulata (Rudolphi, 1802) Odhner, 1910

HOST: *Zalophus californianus*–California sea lion.
LOCATION: Intestine.
LOCALITY: National Zoological Park, Washington, D.C.
RECORDED BY: Price (1932).

CESTODA

Diphyllobothrium lanceolatum (Krabbe, 1865) Meggitt, 1924

HOST: *Erignathus barbatus*–bearded seal.
LOCATION: Intestine.
LOCALITY: St. Lawrence Island, Alaska.
RECORDED BY: Stunkard and Schoenborn (1936); Stunkard (1948).
REMARKS: Wardle, McLeod and Stewart (1947) and Wardle and McLeod (1952) regarded this species as identical with *D. phocarum* (Fabricius, 1780) and placed it in their new genus

Cordicephalus. Stunkard (1948) did not recognize the genus *Cordicephalus*, which he considered as a direct synonym of *Pyramicocephalus*. Markowski (1925a, b) agreed with Stunkard and Schoenborn in identifying this species from the bearded seal as *D. lanceolatum*. He replaced *phocarum*, a species considered quite distinct from *lanceolatum*, in the genus *Pyramicocephalus*.

Diphyllobothrium glaciale (Cholodkovsky, 1915) Markowski, 1952

SYNS.: *Cordicephalus arctocephalinus* (Johnston, 1937) Wardle, McLeod and Stewart, 1947.
Adenocephalus septentrionalis Nybelin, 1931.
Bothriocephalus sp. of Stiles and Hassall, 1899.

HOST: *Callorhinus ursinus*–northern fur seal.

LOCATION: Intestine.

LOCALITY: Pribilof Islands, Alaska.

RECORDED BY: Wardle, McLeod and Stewart (1947); Wardle and McLeod (1952); Stunkard (1948); Stiles and Hassall (1899); Markowski (1952b); Nybelin (1931).

REMARKS: Stiles and Hassall's (1899) *Bothriocephalus* sp. was re-examined by Nybelin (1931), who named the species *Adenocephalus septentrionalis*, and later by Markowski (1952b), who regarded the specimens as identical with *Clestobothrium glaciale*, a species described by Cholodkovsky (1915) from the fur seal off Kamchatka. Markowski placed this species in the genus *Diphyllobothrium*. Wardle, McLeod and Stewart (1947) examined new specimens from the same host and locality as Stiles and Hassall's material and considered the species to be identical with *Diphyllobothrium arctocephalinus* Johnston, 1937, but removed this species to their new genus *Cordicephalus*, which was rejected by Stunkard (1948) and Markowski (1952a, b). Stunkard (1948) described a species from *Callorhinus ursinus*, but left it unnamed. He did not believe this species was identical with *D. arctocephalinus* from antarctic seals, although he considered his material to be the same species as recorded by Stiles and Hassall as *Bothriocephalus* sp. and by Wardle *et al.* as *C. arctocephalinus*. Markowski (1952b) has shown that *D. arctocephalinus* is a synonym of *D. scoticum* (Rennie and Reid, 1912) from antarctic seals, which is distinct from *D. glaciale*. This latter author also considered "species No. 2" of Stunkard (1948) as *D. glaciale*.

Diplogonoporus tetrapterus (von Seibold, 1848) Ariola, 1896

SYN.: *Diplogonoporus* sp. of Stunkard, 1948.

HOST: *Callorhinus ursinus*–northern fur seal.

LOCATION: Intestine.

LOCALITY: St. Paul's Island, Alaska.

RECORDED BY: Stunkard (1948).

REMARKS: Stunkard (1948) described this species in detail but did not assign it to any known species. He stated that it may be identical with *D. tetrapterus* (von Seibold, 1848), *D. variabilis* (Krabbe, 1865) or *D. fasciatus* (Krabbe, 1865). Markowski (1952b) regarded Stunkard's specimens as belonging to the species *tetrapterus*, with *variabilis* as a synonym.

Diplogonoporus fasciatus (Krabbe, 1865) Lühe, 1899

SYN.: *Diplogonoporus* sp. of Stunkard, 1948.

HOST: *Eumetopias jubata*–Steller sea lion.

LOCATION: Intestine.

LOCALITY: St. Paul's Island, Alaska.

RECORDED BY: Stunkard (1948).

REMARKS: Stunkard (1948) believed this species was possibly identical with *D. fasciatus* (Krabbe, 1865), but probably different from the *Diplogonoporus* sp. from the northern fur seal. Markowski (1952b) considered Stunkard's material as *D. fasciatus*.

Pyramicocephalus phocarum (Fabricius, 1780) Braun, 1900

HOST: *Enhydra lutris*–sea otter.
LOCATION: Intestine.
LOCALITY: Amchitka, Aleutian Islands, Alaska.
RECORDED BY: Rausch (1953).

NEMATODA

Uncinaria lucasi Stiles, 1901

SYN.: *Uncinaria* sp. of Stiles and Hassall (1899).
HOST: *Callorhinus ursinus*–northern fur seal.
LOCATION: Intestine.
LOCALITY: Pribilof Islands, Alaska.
RECORDED BY: Stiles and Hassall (1899); Stiles (1901); Baylis (1947).

Uncinaria hamiltoni Baylis, 1933

HOST: (?) *Eumetopias jubata*–Steller sea lion.
LOCATION: Intestine.
LOCALITY: San Francisco, California.
RECORDED BY: Baylis (1933, 1947).
REMARKS: Baylis doubtfully assigned specimens of *Uncinaria*, collected from the sea lion (Steller?) near San Francisco, to this species which he described from a southern sea lion, *Otaria byronia*.

Parafilaroides decorus Dougherty and Herman, 1947

SYN.: *Filaroides* sp. of Dougherty, 1943.
Parafilaroides sp. of Dougherty, 1946.
HOST: *Zalophus californianus*–California sea lion.
LOCATION: Lungs.
LOCALITY: Zoo, San Diego, California.
RECORDED BY: Dougherty (1943b, 1946); Dougherty and Herman (1947).

Parafilaroides nanus Dougherty and Herman, 1947

SYNS.: *Filaroides* sp. of Dougherty, 1943.
Parafilaroides sp. of Dougherty, 1946.
HOST: *Eumetopias jubata*–Steller sea lion.
LOCATION: Lungs.
LOCALITIES: Zoo, San Diego, and/or captive in San Francisco, California.
RECORDED BY: Dougherty (1943b, 1946); Dougherty and Herman (1947).

Parafilaroides prolificus Dougherty and Herman, 1947

SYNS.: *Filaroides* sp. of Dougherty, 1943.
Parafilaroides sp. of Dougherty, 1946.
HOST: *Eumetopias jubata*–Steller sea lion.
LOCATION: Lungs.
LOCALITIES: Zoo, San Diego and/or captive in San Francisco, California.
RECORDED BY: Dougherty (1943b, 1946); Dougherty and Herman (1947).

Parafilaroides sp. Dougherty and Herman, 1947

HOST: *Eumetopias jubata*–Steller sea lion.
LOCATION: Lungs.
LOCALITIES: Zoo, San Diego, or captive in San Francisco, California.
RECORDED BY: Dougherty and Herman (1947).

Stenurus vagans (Eschricht, 1841) Dougherty, 1943

SYN.: *Stenurus phocoenae* Dougherty, 1943.
HOST: *Phocoena vomerina*–harbour porpoise.
LOCATION: Lungs.
LOCALITY: San Francisco Bay, California.
RECORDED BY: Dougherty (1943a, c).

Pharurus convolutus (Kuhn, 1829) Dougherty, 1943

HOST: *Phocoena vomerina*–harbour porpoise.
LOCATION: Lungs.
LOCALITIES: San Francisco Bay, California; Neah Bay, Washington.
RECORDED BY: Dougherty (1943a); Scheffer and Slipp (1948).

Halocercus invaginatus (Queckitt, 1841) Dougherty, 1943

HOST: *Phocoena vomerina*–harbour porpoise.
LOCATION: Lungs.
LOCALITIES: San Francisco Bay, California; Neah Bay, Washington.
RECORDED BY: Dougherty (1943a, 1944); Scheffer and Slipp (1948).

Halocercus kirbyi Dougherty, 1944

SYN.: *Halocercus* sp. of Benson and Groody, 1942, and of Dougherty, 1943.
HOST: *Phocoenoides dalli*–harbour porpoise.
LOCATION: Lungs.
LOCALITY: San Francisco Bay, California.
RECORDED BY: Benson and Groody (1942); Dougherty (1943a, 1944).

Anisakis simplex (Rudolphi, 1809)

HOST: *Balaenoptera borealis*–sei whale.
LOCATION: Stomach.
LOCALITY: Cachalot, British Columbia.
RECORDED BY: Mueller (1927a, b); Cornwall (1928).

Anisakis similis (Baird, 1853) Baylis, 1920

HOSTS: *Zalophus californianus*–California sea lion; *Mirounga angustirostris*–elephant seal; *Eumetopias jubata*–Steller sea lion.
LOCATION: Stomach.
LOCALITIES: Zoo, San Diego, California, Baja California coast; Zoo, Basel, Switzerland.
RECORDED BY: Schroeder and Wegeforth (1935); Caballero and Peregrina (1938); Herman (1942); Kreis (1940).

Anisakis physeteris Baylis, 1923

HOST: *Physeter catodon*–sperm whale.
LOCATION: Stomach and intestine.
LOCALITY: Aleutian Islands, Alaska.
RECORDED BY: Scheffer (1939).

Anisakis tridentatus Kreis, 1938

HOST: *Eumetopias jubata*–Steller sea lion.
LOCATION: Stomach.
LOCALITY: Zoo, Basel, Switzerland.
RECORDED BY: Kreis (1938).

Anisakis typica (Diesing, 1860)

SYNS.: *Ascaris typica* (Diesing, 1860).
Ascaris simplex (Rudolphi, 1809) of Leidy, 1886.

HOST: Unidentified dolphin (*Delphinus* sp.?).
LOCATION: Stomach.
LOCALITY: Pacific.
RECORDED BY: Leidy (1886) identified these specimens as ***Ascaris simplex***; Stiles and Hassall (1899) redetermined them as *Ascaris* (*Anisakis*) ***typica*** (Diesing, 1860).
REMARKS: Lyster (1940) regarded *A. typica* (Diesing, 1860) as a synonym of *A. simplex* (Rudolphi, 1809).

Anisakis sp.

HOST: *Grampus rectipinna*–killer whale.
LOCATION: Intestine.
LOCALITY: Puget Sound, Washington.
RECORDED BY: Scheffer and Slipp (1948).

Porrocaecum decipiens (Krabbe, 1878) Baylis, 1920

SYN.: *Ascaris decipiens* (Krabbe, 1878).

HOSTS: *Callorhinus ursinus*–northern fur seal; *Eumetopias jubata*–Steller sea lion; *Phoca vitulina richardi*–harbour seal; *Enhydra lutris*–sea otter.
LOCATION: Stomach.
LOCALITIES: Pribilof Islands, Alaska; Puget Sound, Washington; British Columbia.
RECORDED BY: Stiles and Hassall (1899); Scheffer and Slipp (1944); Fisher (1952); Rausch (1953).

Porrocaecum sp.

HOST: *Zalophus californianus*–California sea lion.
LOCATION: Stomach.
LOCALITY: Zoological Gardens, San Diego, California.
RECORDED BY: Herman (1942).

Contracaecum osculatum (Rudolphi, 1802) Baylis, 1920

SYN.: *Ascaris osculata* (Rudolphi, 1802).

HOSTS: *Eumetopias jubata*–Steller sea lion; *Phoca vitulina richardi*–harbour seal; *Zalophus californianus*–California sea lion; *Mirounga angustirostris*–elephant seal.
LOCATION: Stomach.
LOCALITIES: Pribilof Islands, Alaska; British Columbia; San Diego Zoo, California.
RECORDED BY: Stiles and Hassall (1899); Fisher (1952); Herman (1942); Caballero and Peregrina (1938).

Dujardinia sp.

HOST: *Zalophus californianus*–California sea lion.
LOCATION: Stomach.
LOCALITY: Zoological Gardens, San Diego, California.
RECORDED BY: Herman (1942).

Dirofilaria immitis (Leidy, 1856) Railliet and Henry, 1911

SYNS.: *Filaria spirocauda* Leidy, 1858 (?).
Dirofilaria spirocauda (Leidy, 1858) *sub judice* Faust, 1937.

HOST: *Zalophus californianus*–California sea lion.
LOCATION: Heart.

LOCALITY: Zoological Garden, New Orleans, Louisiana (animal caught at Sea Cliffs, California).

RECORDED BY: Faust (1937).

REMARKS: Faust found his specimens to be morphologically identical with the type specimen of *D. immitis*. The type specimen of *F. spirocauda* has not been located, but Faust considered the evidence strong enough to place this species in the genus *Dirofilaria*. *Dirofilaria spirocauda* (i.e. *F. spirocauda*) was described from *Phoca vitulina* and Faust considered that this species is probably identical with his individuals from the sea lion and consequently a probable synonym of *D. immitis*. Anderson (1952) placed *Filaria spirocauda* Leidy) and *Dirofilaria spirocauda* (Leidy) *sub judice* as synonyms of *D. immitis*.

ACANTHOCEPHALA

Corynosoma strumosum (Rudolphi, 1802)

SYN.: *Corynosoma osmeri* Fujita, 1921.

HOSTS: *Phoca vitulina richardi*–harbour seal; *Zalophus californianus*–california sea lion; *Halichoerus grypus*–grey seal; *Callorhinus ursinus*–northern fur seal; *Enhydra lutris*–sea otter; unidentified seals.

LOCATION: Intestine.

LOCALITIES: Puget Sound, Washington; Point Mugu, Ventura County, California; Zoological Gardens, San Diego, California; Aleutian Islands and Pribilof Islands, Alaska.

RECORDED BY: Ball (1930); Scheffer and Slipp (1944); Lincicome (1943); van Cleave (1953a, b); Rausch (1953).

REMARKS: van Cleave (1953a, b) considered *C. osmeri* Fujita, 1921, recorded by Lincicome (1943) from the California sea lion, as a synonym of *C. strumosum*.

Corynosoma semerme (Forsell, 1904)

HOSTS: *Phoca vitulina richardi*–harbour seal; *Callorhinus ursinus*–northern fur seal; unidentified seals.

LOCATION: Intestine.

LOCALITIES: British Columbia; Pribilof and St. Lawrence Islands, Alaska.

RECORDED BY: Fisher (1952); van Cleave (1953b).

REMARKS: The specimens from the harbour seal, referred to by Fisher as *C. semerme*, were probably misidentified specimens of *C. strumosum*. Specimens of this latter species have been identified from the harbour seal in British Columbia by the present author (unpublished).

Corynosoma villosum van Cleave, 1953

SYN.: *Corynosoma* sp. Rausch and Locker, 1951.

HOSTS: *Callorhinus ursinus*–northern fur seal; *Enhydra lutris*–sea otter; *Eumetopias jubata*–Steller sea lion; unidentified seal.

LOCATION: Intestine.

LOCALITIES: Various islands in Bering Sea off the coast of Alaska.

RECORDED BY: van Cleave (1953a, b); Rausch and Locker (1951).

Corynosoma validum van Cleave, 1953

HOSTS: *Odobenus divergens*–Pacific walrus; unidentified seal.

LOCATION: Intestine.

LOCALITY: St. Lawrence Island, Alaska.

RECORDED BY: van Cleave (1953a, b).

Corynosoma hadweni van Cleave, 1953

HOSTS: *Halichoerus grypus*–grey seal; unidentified seals.

LOCATION: Intestine.

LOCALITIES: Aleutian Islands and St. Lawrence Island, Alaska.

RECORDED BY: van Cleave (1953a, b).

Corynosoma falcatum van Cleave, 1953

HOST: *Halichoerus grypus*–grey seal.
LOCATION: Intestine.
LOCALITY: Aleutian Islands, Alaska.
RECORDED BY: van Cleave (1953a, b).

Corynosoma obtuscens Lincicome, 1943

HOST: *Zalophus californianus*–California sea lion.
LOCATION: Intestine.
LOCALITY: Zoological Gardens, San Diego, California.
RECORDED BY: Lincicome (1943); van Cleave (1953a, b).

Bolbosoma balanae (Gmelin, 1790) Meyer, 1932

HOST: Unidentified species of whale.
LOCATION: Intestine.
LOCALITY: Seattle, Washington.
RECORDED BY: van Cleave (1953b).

COPEPODA

Pennella balaenopterae Koren and Danielssen, 1877

HOST: *Balaenoptera physalus*–fin whale.
LOCATION: Head embedded in skin.
LOCALITY: Cachalot, British Columbia.
RECORDED BY: Cornwall (1927, 1928).

CIRRIPEDIA

Conchoderma auritum (Linnaeus, 1767) Olfers, 1814

SYN.: *Otion stimpsoni* Dall, 1872.
HOST: *Megaptera nodosa*–humpback whale.
LOCATION: Attached to *C. diadema* on skin.
LOCALITIES: Cachalot, British Columbia; California; Alaska.
RECORDED BY: Dall (1872b); Scammon (1874); Pilsbry (1907); Cornwall (1924, 1927); Scheffer (1939).
REMARKS: Pilsbry (1907) considered Dall's species, *Otion stimpsoni*, a synonym of *C. auritum*.

Coronula diadema (Linnaeus, 1767) Lamarck, 1818

HOST: *Megaptera nodosa*–humpback whale.
LOCATION: Skin.
LOCALITIES: Many points from Bering Strait to Southern California.
RECORDED BY: Dall (1872b); Pilsbry (1916); Cornwall (1924, 1927); Scheffer (1939).
REMARKS: Dall (1872b) recorded some specimens from the humpback whale, which are probably referable to *C. diadema*, under the name *Coronula balaenaris* (the latter a *nomen nudum* according to Pilsbry, 1916).

Coronula reginae Darwin, 1854

HOST: *Megaptera nodosa*–humpback whale.
LOCATION: Skin.
LOCALITIES: Aleutian Islands, Alaska; Cachalot, British Columbia; mouth of Umpqua River, Oregon.
RECORDED BY: Dall (1872b); Cornwall (1927); Pilsbry (1916).

Cryptolepas rachianecti Dall, 1872

HOST: *Rhachianectes glaucus*–California grey whale.
LOCATION: Skin.
LOCALITIES: Monterey, California; Neah Bay, Washington; Bering Island.
RECORDED BY: Dall (1872b); Pilsbry (1916).

Xenobalanus globicipitis Steenstrup, 1851

HOST: *Balaenoptera borealis*–sei whale.
LOCATION: Skin of flipper.
LOCALITY: Cachalot, British Columbia.
RECORDED BY: Cornwall, (1927).

AMPHIPODA

Cyamus ceti Linnaeus, 1754

SYNS.: *Cyamus mysticeti* Lütken, 1870.
Cyamus mysticeti Dall, 1872.

HOST: *Balaena mysticetus*–northern bow-head whale.
LOCATION: Skin.
LOCALITY: Near Bering Strait, Alaska.
RECORDED BY: Dall (1872b); Scammon (1874).

Cyamus ovalis R. de Vauzème, 1834

SYN.: *Cyamus tentator* Dall, 1874.

HOST: *Balaena glacialis*–black right whale.
LOCATION: Skin.
LOCALITY: Island of Kodiak, Alaska.
RECORDED BY: Dall (1874).
REMARKS: Lütken (1887) redetermined Dall's specimens as *C. ovalis*. The host was recorded by Dall as *Balaena Siebodii* (a lapsus for *Sieboldii*)–Pacific right whale.

Cyamus scamoni Dall, 1872

HOST: *Rhachianectes glaucus*–California grey whale.
LOCATION: Skin.
LOCALITY: California coast.
RECORDED BY: Dall (1827a); Scammon (1874); Lütken (1887).

Paracyamus boopis (Lütken, 1870) Sars, 1895

SYNS.: *Cyamus boopis* Lütken, 1870.
Cyamus suffusus Dall, 1872.
Cyamus pacificus Lütken, 1873.

HOST: *Megaptera nodosa*–humpback whale.
LOCATION: Skin.
LOCALITIES: Cachalot, British Columbia; Monterey, California; Aleutian Islands, Alaska.
RECORDED BY: Dall (1872a, b); Scammon (1874); Lütken (1873, 1887); Cornwall (1928); Scheffer (1939).
REMARKS: Dall (1872a, b) described *Cyamus suffusus* as a new species from the humpback whale in California seas. Lütken (1870) had already briefly characterized and named the parasite *Cyamus boopis* from the humpback whale of European waters. In a postscript to a paper published in 1873, Lütken considered *C. suffusus* as a possible synonym of *Cyamus pacificus*, a new species described by him from an unspecified whale caught off the Pacific coast of Panama. *Cyamus pacificus* was considered, by its author, as very closely related to, if not identical with *C. boopis*. In a later paper, Lütken (1887), after examining specimens

of *C. suffusus* obtained from Dall, considered this cyamid identical with *C. pacificus* and the latter species almost certainly co-specific with *C. boopis*. Stebbing (1910) and Barnard (1932) regarded *pacificus* (and hence *suffusus*) as definitely synonymous with *boopis*. Sars (1895) had previously introduced a new genus, *Paracyamus*, for Lütken's *C. boopis*, the parasite thus becoming known as *Paracyamus boopis* (Lütken, 1870) Sars, 1895.

Paracyamus gracilis (R. de Vauzème, 1834) Barnard, 1932

SYN.: *Cyamus gracilis* Dall, 1874.

HOST: *Balaena glacialis*–black right whale.
LOCATION: Skin.
LOCALITY: Island of Kodiak, Alaska.
RECORDED BY: Dall (1874).
REMARKS: Lütken (1887) re-examined Dall's specimens and found them to be identical with *Cyamus gracilis* R. de Vauzème, 1834 (=*Paracyamus gracilis*). Dall recorded the host as *Balaena Siebodii* (a lapsus for *Sieboldii*)–Pacific right whale.

ACARINA

Halarachne halichoeri Allman, 1847

HOST: *Phoca vitulina richardi*–harbour seal.
LOCATION: Naso-pharynx.
LOCALITIES: Puget Sound, Washington; Pacific Grove, California.
RECORDED BY: Ferris (1925, 1942); Scheffer and Slipp (1944).
REMARKS: Ferris (1925) identified specimens from Pacific Grove as *H. otariae* Steding, 1923. In 1942 he redetermined these specimens as *H. halichoeri*. Newell (1947) doubted the existence of this species on the Pacific coast of North America.

Halarachne miroungae Ferris, 1925

HOSTS: *Mirounga angustirostris*–elephant seal; *Phoca vitulina richardi*–harbour seal.
LOCATION: Naso-pharynx.
LOCALITIES: Baja California coast; Zoo, San Diego, California.
RECORDED BY: Ferris (1925, 1942); Doetschman (1941); Newell, (1947).

Orthohalarachne attenuata (Banks, 1910) Newell, 1947

SYN.: *Halarachne attenuata* Banks, 1910.

HOST: *Callorhinus ursinus*–northern fur seal; *Eumetopias jubata*–Stellar sea lion.
LOCATION: Naso-pharynx.
LOCALITIES: Pribilof Islands, Alaska; Depoe Bay, Oregon.
RECORDED BY: Banks (1910); Oudemans (1926); Newell (1947).
REMARKS: Newell (1947) created the new genus *Orthohalarachne* with *Halarachne attenuata* Banks, 1910, as the type species.

Orthohalarachne zalophi (Oudemans, 1916) Newell, 1947

SYNS.: *Halarachne zalophi* Oudemans, 1916.
Halarachne otariae Steding, 1923.

HOSTS: *Zalophus californianus*–California sea lion; *Eumetopias jubata*–Stellar sea lion.
LOCATION: Naso-pharynx.
LOCALITIES: Göttingen, Germany; Zoo, San Diego, California; Pacific Grove, California.
RECORDED BY: Oudemans (1916, 1926); Steding (1923); Doetschman (1941); Ferris (1942); Newell (1947).
REMARKS: Oudemans (1916) and Steding (1923) described *H. zalophi* and *H. otariae* respectively from the same California sea lion in Göttingen. Ferris (1942) and Newell (1947) considered *H. otariae* identical with *H. zalophi*. Newell placed the species in his new genus *Orthohalarachne*.

Orthohalarachne diminuata (Doetschman, 1944) Newell, 1947

SYN.: *Halarachne diminuata* Doetschman, 1944.

HOSTS: *Zalophus californianus*–California sea lion; *Callorhinus ursinus*–northern fur seal.
LOCATION: Bronchioles and trachea.
LOCALITIES: Zoo, San Diego, California; St. Paul Island, Alaska.
RECORDED BY: Doetschman (1944); Newell (1947).
REMARKS: Newell (1947) placed *H. diminuata* in his new genus *Orthohalarachne*.

Halarachne sp.

HOST: *Eumetopias jubata*–Stellar sea lion.
LOCATION: Naso-pharynx (?).
LOCALITY: Pacific Grove, California.
RECORDED BY: Ferris (1942).

Halarachne sp.

HOST: *Phoca vitulina richardi*–harbour seal.
LOCATION: Naso-pharynx.
LOCALITY: British Columbia.
RECORDED BY: Fisher (1952).

ANOPLURA

Echinophthirius horridus (Olfers, 1816) Fahrenholz, 1919

HOST: *Phoca vitulina richardi*–harbour seal.
LOCATION: Skin.
LOCALITY: Pacific Grove, California.
RECORDED BY: Ferris (1934, 1951).

Proechinophthirus fluctus (Ferris, 1916) Ewing, 1923

SYN.: *Echinophthirius fluctus* Ferris, 1916.

HOSTS: *Callorhinus ursinus*–northern fur seal; *Eumetopias jubata*–Steller sea lion.
LOCATION: Skin.
LOCALITIES: Museum, Stanford University, California; Pribilof Islands, Alaska.
RECORDED BY: Ferris (1916, 1934, 1951); Ewing (1923); McAtee (1923).

Antarctophthirus microchir (Trouessart and Newman, 1888) Enderlein, 1906

HOSTS: *Zalophus californianus*–California sea lion; *Eumetopias jubata*–Stellar sea lion.
LOCATION: Skin.
LOCALITIES: California; Pribilof Islands, Alaska.
RECORDED BY: Ferris (1916, 1934, 1951); Jellison (1952).

Antarctophthirus callorhini (Osborn, 1899) McAtee, 1923

SYNS.: *Haematopinus callorhini* Osborn, 1899.
Antarctophthirus monachus Kellogg and Ferris, 1915.

HOST: *Callorhinus ursinus*–northern fur seal.
LOCATION: Skin.
LOCALITY: Pribilof Islands, Alaska.
RECORDED BY: Osborn (1899); Kellogg and Ferris (1915); AcAtee (1923); Ferris (1934, 1951); Jellison (1952).

CYCLOSTOMATA

Entosphenus tridentatus (Gairdner, 1836)

HOSTS: *Balaenoptera borealis*–sei whale; *Balaenoptera physalus*–fin whale; *Megaptera nodosa*–humpback whale; *Physeter catodon*–sperm whale.

LOCATION: Temporarily attached to skin.
LOCALITY: British Columbia.
RECORDED BY: Pike (1951).

HOST-PARASITE LIST

CETACEA

Balaena glacialis–black right whale
AMPHIPODA: *Cyamus ovalis* R. de Vauzème, 1834, *Paracyamus gracilis* (R. de Vauzème, 1834).

Balaena mysticetus–northern bow-head whale
AMPHIPODA: *Cyamus ceti* Linnaeus, 1754.

Balaenoptera borealis–sei whale
NEMATODA: *Anisakis simplex* (Rudolphi, 1809).
CIRRIPEDIA: *Xenobalanus globicipitis* Steenstrup, 1851.
CYCLOSTOMATA: *Entosphenus tridentatus* (Gairdner, 1836).

Balaenoptera physalus–fin whale
COPEPODA: *Pennella balaenopterae* Koren and Danielssen, 1877.
CYCLOSTOMATA: *Entosphenus tridentatus* (Gairdner, 1836).

Delphinapterus leucas–white whale
TREMATODA: *Hadwenius seymouri* Price, 1932.

Delphinus sp. (unidentified dolphin)
NEMATODA: *Anisakis typica* (Deising, 1860).

Grampus rectipinna–killer whale
NEMATODA: *Anisakis* sp.

Megaptera nodosa–humpback whale
CIRRIPEDIA: *Conchoderma auritum* (Linnaeus, 1767), *Coronula diadema* (Linnaeus, 1767), *Coronula reginae* Darwin, 1854.
AMPHIPODA: *Paracyamus boopis* (Lütken, 1871).
CYCLOSTOMATA: *Entosphenus tridentatus* (Gairdner, 1836).

Phocoena vomerina–harbour porpoise
NEMATODA: *Pharurus convolutus* (Kuhn, 1829), *Halocercus invaginatus* (Queckitt, 1841), *Stenurus vagans* (Eschricht, 1841).

Phocoenoides dalli–dall porpoise
NEMATODA: *Halocercus kirbyi* Dougherty, 1944.

Physeter catodon–sperm whale
NEMATODA: *Anisakis physeteris* Baylis, 1923.
CYCLOSTOMATA: *Entosphenus tridentatus* (Gairdner, 1836).

Rhachianectes glaucus–California grey whale
CIRRIPEDIA: *Cryptolepas rachianecti* Dall, 1872.

Unidentified species of whale
ACANTHOCEPHALA: *Bolbosoma balaenae* (Gmelin, 1790).

PINNIPEDIA

Callorhinus ursinus–northern fur seal

CESTODA: *Diphyllobothrium glaciale* (Cholodkovsky, 1915), *Diplogonoporus tetrapterus* (von Siebold, 1848).

NEMATODA: *Uncinaria lucasi* Stiles, 1901, *Porrocaecum decipiens* (Krabbe, 1878).

ACANTHOCEPHALA: *Corynosoma villosum* van Cleave, 1953, *Corynosoma strumosum* (Rudolphi, 1802), *Corynosoma semerme* Forsell, 1904.

ACARINA: *Orthohalarachne attenuata* (Banks, 1910), *Orthohalarachne diminuata* (Doetschman, 1944).

ANOPLURA: *Antarctophthirus callorhini* (Osborn, 1899), *Proechinophthirus fluctus* (Ferris, 1916).

Erignathus barbatus–bearded seal

TREMATODA: *Orthosplanchnus fraterculus* Odhner, 1905.

CESTODA: *Diphyllobothrium lanceolatum* (Krabbe, 1865).

Eumetopias jubata–Steller sea lion

CESTODA: *Diplogonoporus fasciatus* (Krabbe, 1865).

NEMATODA: *Anisakis similis* (Baird, 1853), *Anisakis tridentatus* Kreis, 1938, *Porrocaecum decipiens* (Krabbe, 1878), *Contracaecum osculatum* (Rudolphi, 1802), *Uncinaria hamiltoni* Baylis, 1933, *Parafilaroides nanus* Dougherty and Herman, 1947, *Parafilaroides prolificus* Dougherty and Herman, 1947, *Parafilaroides* sp. of Dougherty and Herman, 1947.

ACANTHOCEPHALA: *Corynosoma villosum* van Cleave, 1953.

ACARINA: *Orthohalarachne attenuata* (Banks, 1910), *Orthohalarachne zalophi* (Oudemans, 1916).

ANOPLURA: *Proechinophthirus fluctus* (Ferris, 1916), *Antarctophthirus microchir* (Trouessart and Neumann, 1888).

Halichoerus grypus–grey seal

ACANTHOCEPHALA: *Corynosoma hadweni* van Cleave, 1953, *Corynosoma strumosum* (Rudolphi, 1802), *Corynosoma falcatum* van Cleave, 1953.

Odobenus divergens–Pacific walrus

ACANTHOCEPHALA: *Corynosoma validum* van Cleave, 1953.

Mirounga angustirostris–elephant seal

NEMATODA: *Anisakis similis* (Baird, 1853), *Contracaecum osculatum* (Rudolphi, 1802).

ACARINA: *Halarachne miroungae* Ferris, 1925.

Phoca vitulina richardi–harbour seal

TREMATODA: *Phocitrema fusiforme* Goto and Ozaki, 1930.

NEMATODA: *Porrocaecum decipiens* (Krabbe, 1802), *Contracaecum osculatum* (Rudolphi, 1802).

ACANTHOCEPHALA: *Corynosoma strumosum* (Rudolphi, 1802). [*Corynosoma semerme* (Forsell, 1904)–probably a misidentification of *C. strumosum* specimens.]

ACARINA: *Halarachne miroungae* Ferris, 1925, *Halarachne halichoeri* Allman, 1847, *Halarachne* sp. of Fisher, 1950.

ANOPLURA: *Echinophthirius horridus* (von Olfers, 1816).

Unidentified species of seal

ACANTHOCEPHALA: *Corynosoma hadweni* van Cleave, 1953, *Corynosoma strumosum* (Rudolphi, 1802), *Corynosoma semerme* Forsell, 1904, *Corynosoma villosum* van Cleave, 1953, *Corynosoma validum* van Cleave, 1953.

Zalophus californianus–California sea lion

TREMATODA: *Zalophotrema hepaticum* Stunkard and Alvey, 1929, *Pricetrema zalophi* (Price, 1932), *Stephanoprora denticulata* (Rudolphi, 1802).

NEMATODA: *Anisakis similis* (Baird, 1853), *Porrocaecum* sp. of Herman, 1942, *Contracaecum osculatum* (Rudolphi, 1802), *Dujardinia* sp. of Herman, 1942, *Parafilaroides decorus* Dougherty and Herman, 1947, *Dirofilaria immitis* (Leidy, 1856).

ACANTHOCEPHALA: *Corynosoma strumosum* (Rudolphi, 1802), *Corynosoma obtuscens* Lincicome, 1943.

ACARINA: *Orthohalarachne zalophi* Oudemans (1916), *Orthohalarachne diminuata* Doetschman, 1944.

ANOPLURA: *Antarctophthirus microchir* (Trouessart and Neumann, 1888).

FISSIPEDIA

Enhydra lutris–sea otter

TREMATODA: *Orthosplanchnus fraterculus* Odhner, 1905, *Phocitrema fusiforme* Goto and Ozaki, 1930, *Microphallus pirum* (Afanasev, 1941), *Pricetrema zalophi* (Price, 1932).

CESTODA: *Pyramicocephalus phocarum* (Fabricius, 1780).

ACANTHOCEPHALA: *Corynosoma villosum* van Cleave, 1953, *Corynosoma strumosum* (Rudolphi, 1802).

NEMATODA: *Porrocaecum decipiens* (Krabbe, 1878).

APPENDIX

Schroeder and Wegeforth (1935) reported stomach nematodes from the California sea lion, elephant seal, harbour seal and Galapagos fur seal (*Arctocephalus galapagensis*) as having been identified as *Anisakis similis* and *Contracaecum osculatum* by Dr. E. W. Price. The authors did not indicate in which pinniped(s) each of the nematode species was found, except in the case of the California sea lion. A photograph of a stomach ulcer with worms bears the caption: "Ulcer crater, California sea lion, male, adult, imbedded with *Anisikis similis* ad." *Anisikis* was undoubtedly a *lapsus* for *Anisakis*. Other parasites of the four pinnipeds mentioned above, recorded by Schroeder and Wegeforth, are the mite *Halarachne miroungae* Ferris, acanthocephalids of the genus *Corynosoma* and the liver fluke, *Zalophotrema hepaticum*. Again the individual hosts of these parasites were not listed. These pinnipeds were from the coast of Baja California or the Zoological Gardens, San Diego, California.

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Tagging Returns, Age Studies and Fluctuations in Abundance of Lake Winnipeg Whitefish, 1931-1951[1]

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ABSTRACT

On the basis of 2,003 lake whitefish, *Coregonus clupeaformis*, tagged in 1938, of which 126 were recovered during the next five years, there is evidence that fish released together tend to stay together for years, and that the proportion of a population captured during a certain time by a unit amount of fishing effort can fluctuate greatly (a plausible explanation is the effect of variations in weather conditions). On the basis of age determinations of 12,975 whitefish in samples taken annually from 1937 to 1951, growth rate was determined, the total annual mortality rate among fully exploited fish was calculated to be 64 per cent over several years, and it appeared that all year-classes had been of about equal strength in recent years. The generally accepted idea that fluctations in fishing success correspond to fluctuations in abundance of whitefish is probably erroneous. Possibly the Lake Winnipeg whitefish are underfished.

INTRODUCTION

The Central Fisheries Research Station of the Fisheries Research Board of Canada is carrying out an investigation which involves the commercial fish of Lake Winnipeg, and in particular the lake whitefish, *Coregonus clupeaformis*. In this connection the Department of Mines and Natural Resources of the Manitoba Government has generously made available to the author certain pertinent information which it has accumulated on Lake Winnipeg whitefish. Although the data leave much to be desired, they are the only data of their kind available for most of the period in question (the Central Fisheries Research Station started collecting data in 1948), and are therefore of great interest as background material. It is the purpose of this paper to record this information for future reference and to draw such tentative conclusions as the limited nature of the data justifies.

MATERIAL AND METHODS

In 1937 the late David Hinks, as an employee of the Manitoba Government, initiated a scientific study of Lake Winnipeg which included the collection of scale samples from whitefish. He continued to collect them until he enlisted in the R.C.A.F. in 1940. For the next three years similar collections were made by Mr. G. E. Butler. During the years 1944 to 1951, inclusive, scale samples were taken by various employees of the Manitoba Government from all the fish used in annual routine inspections for possible infection with pleroceroids of *Triaenophorus crassus*. Individual weights were recorded only for the scale samples taken during the period 1944–51, inclusive. The samples collected in 1937, 1938 and 1939 were taken in October, in nets used by the Provincial Government to capture spawning fish (except that about one-third of those taken in 1938 were

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from the commercial catch) hence are not necessarily representative of the commercial catch. The samples collected from 1940 to 1943, inclusive, were taken from the commercial catch during the summer but, except for the 1942 sample, were taken at only two places, hence may not be altogether representative of the whole fishery. The samples taken from 1944 to 1951, inclusive, are regarded as more nearly representative of the commercial catches. Although in these years the collecting of scale samples was incidental to an entirely different investigation, the fish chosen were taken at places scattered over the entire fishing grounds, and instructions regarding procedure were designed to ensure a random sample of fish at each place. In general, samples were taken only once per year (not always at the same time) so that they are not necessarily representative of the whole year.

A few scales from each fish were later magnified about 30 times (a magnification of 60 was used in special cases) by means of a microprojector, and the number of annuli on the projected image was counted. Although several people made preliminary readings on these scales, all final decisions on the number of annuli were made by either Ellen Johanson or Dawn Brown, technicians employed solely to read scales. In a group of representative readings the author agreed in most cases with the interpretations of the technicians and they agreed with one another. As an example of the way ages are designated in the paper, an "age-10" fish is one that has lived 10 full years and is in its eleventh year of life.

Mr. Hinks also tagged and released over 2,000 whitefish which had been captured late in 1938 to obtain spawn for a fish hatchery. No reward was offered for returning these tags. The recovery of 126 of them was reported voluntarily by commercial fishermen and by Fisheries Officers. Records of the original tagging and of the recoveries were made available to the Central Fisheries Research Station by the Manitoba Government.

THE FISHING GROUNDS

The centre of Lake Winnipeg (see Figure 1) lies approximately at Lat. 52° N. and Long. 98° W. Its long axis runs roughly north and south (actually more nearly NW. by N. and SE. by S.). It is about 250 miles long and the maximum width is about 65 miles. The area, as calculated from recent maps, is 9,094 square miles, of which a calculated 8,829 square miles are water and 265 square miles are islands. The average depth is estimated to be 43 feet so there is about 11×10^{12} cubic feet of water.

The contact line between the Canadian Shield and the Ordovician formation lies within the lake near the east shore. Thus the eastern shoreline is mostly Pre-Cambrian rock, quite irregular, with many small rocky islands and shoals lying offshore, whereas the western shoreline is more regular with beaches of limestone rubble or with limestone cliffs in many places. Most of the lake bottom is clay or mud.

Over the period from the early 1930's until 1951 a major part of the whitefish produced were caught during the summer season, which typically embraces most of June, all of July, and a few days in August. Most of them were caught

in the "whitefish area" which may be defined roughly as the area lying north of a line from Catfish Creek to Kinwow Bay. In recent years about one-quarter of the annual catch was taken outside the whitefish area, or during other seasons.

The whitefish area comprises slightly more than 70 per cent of the total water area of the lake, that is, about 6,300 square miles. Although the maximum depth in this area is just over 60 feet, the average depth is 49 feet, with about 70 per cent of the area over 40 feet—an indication of the fact that depth increases for only the first few miles offshore, and that the bottom of the whole centre of the lake is relatively flat. Within the whitefish area a major portion, but by no means all, of the whitefish are caught within a few miles of the eastern, that is the Pre-Cambrian, shore.

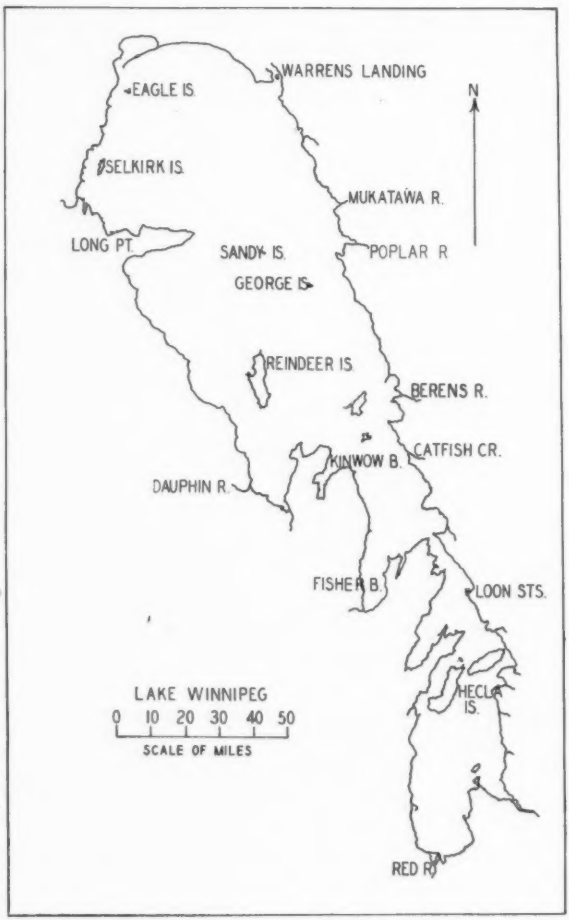

FIGURE 1. A map of Lake Winnipeg.

THE FISHERY

The early history of the fishery is obscure, but as nearly as can be ascertained it is as follows. Fishing began on a small scale toward the end of the nineteenth century in the southernmost part of the lake. As time went on the fishing intensity increased and more fish were taken. At the same time fishing was extended to the north, and finally the whitefish area as defined above became the main fishing grounds. At first the west shore of the whitefish area was fished to a much greater extent than it is now. On the original fishing grounds at the south end of the lake, whitefish became rare about 1920 or earlier.

Until about 1930 most of the fishing was done by gill-nets from sailboats which were about 35 feet long. In many cases steam tugs towed groups of sailboats to the fishing grounds, and gill-nets were also fished from the tugs until it was time to tow their respective convoys of sailboats back to port. By the early 1930's the sailboats were replaced by gasoline-powered boats, fishing from steam tugs was discontinued, and the boats and gear became essentially what they are today.

The boats now used are about 40–45 feet long, round bottomed and sturdily built of wood. They are open boats except for a small deckhouse amidships over the gasoline motor. From each boat about 5,000 yards of gill-nets of 5¼-inch mesh (stretched measure) are fished and are pulled by hand. These nets are lifted daily except in extremely bad weather. A unique feature of the fishery is a law[2] requiring all nets to be out of the water over Sunday—they are pulled out on Saturday, taken ashore and not re-set until Monday, hence they are only fished for five-sevenths of the time. Another unique feature is that each fisherman is not permitted to take more than a specified weight of fish in any one season—when he reaches his "limit" he pulls out his nets and leaves the whitefish area.

Although this brief description of the present fishery applies in general to the whole period since the early 1930's, there have been some changes which are particularly significant because they have increased the efficiency of the gear. An early change was the general substitution of nets 30 meshes deep for the nets 20 meshes deep that had been used before that. Gradually the twine in the web was made finer and finer. Finally, starting in 1949, the substitution of nylon twine for cotton began and by 1951 about one-third of the nets were nylon. Each of these changes would be expected to increase fishing efficiency so that, if the fish population remained unchanged, the catch per boat would presumably increase, or alternatively a failure to increase catch per boat could be interpreted as indicating a reduced population.

Approximately the same number of boats were engaged in the fishery from the early 1930's until 1951. The fishing methods and the amount of gear per boat remained relatively unchanged, and the efficiency of the gear changed only slowly. A comparison of production totals from summer to summer might be expected to indicate whether there had been any major fluctuations in availability (i.e. in catch per unit of fishing effort). Unfortunately several circumstances make the total catch an unreliable index. Some of these circumstances

[2]In 1953 the law was changed to allow fishing for seven days a week.

are: Fishermen were prohibited by law from catching more than a specific amount of fish in any summer; when fishing was good (i.e. in years when availability was noticeably greater than average) the fish-handling facilities were inadequate for all the fish that could be caught, and the fishermen had to fish less than the usual amount of gear; and when fishing was good the buyers rejected a greater proportion and the rejected fish were not included in the reported production. However, for what they are worth, total catches according to the Manitoba Government's statistical records are recorded in the first column of Table I. The second column shows what proportion of the total catch was taken in the whitefish area during the summer. It was noted in preparing Table I

TABLE I. Production of Lake Winnipeg whitefish and related information according to the records of the Manitoba Government.

Year	Annual catch in millions of pounds	Percentage caught in summer in whitefish area	Summer limit, millions of pounds	No. boats licensed for summer	No. spawning fish captured at Dauphin River	October water levels in ft. above sea level
1931	3.6	..	3.0	70	..	..
1932	4.6	..	3.0	76	9,900	710.6
1933	5.3	..	4.0	95	13,700	711.5
1934	3.9	..	3.0	121	9,100	712.7
1935	2.5	..	3.0	164	1,000	712.8
1936	0.7	..	3.0	166	1,000	712.2
1937	2.0	..	2.0	132	500	711.8
1938	2.1	..	2.0	174	700	712.0
1939	2.0	..	1.7	69	1,100	711.2
1940	3.5	..	2.6	118	10,000	710.0
1941	4.0	72	2.9	136	17,000	710.0
1942	4.1	65	3.0	150	5,400	712.2
1943	3.7	76	3.0	150	5,200	713.1
1944	2.4	80	3.0	150	1,100	713.0
1945	2.7	82	3.0	150	300	713.0
1946	2.4	87	3.0	150	400	712.9
1947	1.8	69	3.0	150	500	714.2
1948	1.5	72	3.0	150	[a]	..
1949	2.4	56	3.0	150	[a]	..
1950	3.5	61	3.0	150	[a]	..
1951	2.7	74	3.0	150	[a]	..

[a]Too few spawners to make the fishery worthwhile.

that the statistical records do not necessarily indicate a relationship between the size of summer catches in the whitefish area and the size of catches at other seasons and places. The third column indicates the maximum catch that all the fishermen combined were allowed to take from the whitefish area during each summer. The fourth column indicates the number of boats fishing in the whitefish area during the summer. The other columns will be mentioned later.

The author has talked to many fishermen and administrators about the history of the fishery, and they seem to be in general agreement on the following:

Fishing was moderately good in the early 1930's, then declined, until in 1936 fishing success reached an all-time low. There was a gradual recovery until 1940 and 1941, when there was unusually good fishing (i.e. a tremendous catch per unit of fishing effort). Starting in 1942, fishing success declined until about 1947, after which it improved slightly but still was not considered satisfactory. According to information from those involved, the values given in Table I do not properly indicate how much 1940 and 1941 differed from other recent years with respect to availability during the summer in the whitefish area. In those two years, apparently, availability became so great that shore facilities were completely inadequate to handle the potential catch, and the fish companies drastically limited the quantity that they would buy from each fisherman. The fishermen reduced their fishing effort until they were only fishing about one-tenth of their usual amount of gear. Even then the fish companies culled out large quantities of fish which normally would have been accepted and those culls were not recorded as part of the catch. Even though the extraordinarily good fishing prevailed for only part of the summer, it is obvious that availability must have been several times as great in 1940 and 1941 as it was in any other recent summer season in the whitefish area.

For years other than 1940 and 1941, because the summer limit was not reached, Table I may give a rough idea of comparative availabilities, except that in some of the years prior to 1935 there was apparently phenomonally good fishing, with reduction in amount of gear fished and drastic culling as in 1940 and 1941. Some fishermen say that 1939 was also a phenomonally good year, but most of them do not remember it as such.

The good fishing of 1940 and 1941 is mentioned several times below. It is important to realize that reference is made in each case to unusually high availability, as attested in verbal statements with which all who observed it agree, rather than to recorded production, which apparently fell far below potential production in those two years.

TAGGING RETURNS

Between October 27 and November 14, 1938, a total of 2,003 whitefish were tagged with a strap tag on the operculum, and released alive into Lake Winnipeg at the mouth of the Dauphin River, located at the southwest "corner" of the whitefish area. Most, if not all, of these fish were ready to spawn when captured. Slightly more than one-half of them had been captured at the mouth of the Dauphin River, while the rest had been captured just off the mouth of the Poplar River (see Figure 1). In the various analyses that follow, place of capture is disregarded, since there was no clear-cut difference between the two groups in subsequent behaviour. There were about four males tagged for every female, and approximately the same sex ratio prevailed among the tagged fish that were recovered. The fact that Lake Winnipeg fishermen tend to concentrate their fishing effort on a few places at any one time may be significant in connection with tagging returns.

Although no reward was offered, 126 tags were eventually recovered and

reported. One of the tags was recovered in Lake St. Martin, about 30 miles up the Dauphin River from the tagging station, and two were recovered in Playgreen Lake, into which Lake Winnipeg drains. Twenty-five tags were recovered close to the point of tagging during the winter fishing season that followed immediately after the tagging. In each of the next two spawning seasons one tag was recovered during spawn-taking operations, and one tagged fish was taken during the winter fishing season two years after tagging. The remaining 95 tagged whitefish were recaptured by commercial fishermen in the whitefish area during the 1939, 1940, 1941, 1942, and 1943 summer fishing seasons, and only those fish are considered in the rest of this section. Because of the general interest shown by the commercial fishermen, it seems probable that at least one-half of the tagged fish that they recovered were reported.

There were, say, 200 occasions on which tagged fish could have been recaptured by commercial fishermen during the summer fishing seasons (tags came in for five years, the summer season lasts about eight weeks, and fish are caught on five days per week). Of the presumed 200 opportunities for having a tag recovered and reported, 122 produced no results, 64 led to reports of single tags recovered, 11 to reports of two tags recovered on the same day, and on each of three occasions three tags were reported as recovered simultaneously. The distribution of these values is not significantly different from that of the Poisson series (Snedecor, 1946, Chapter 16) for which the corresponding values are 125, 59, 14 and 2. The relationship between number of tagged fish recovered and the number actually reported is of course unknown, but probably the number of tags recovered was also more or less a Poisson series, perhaps with greater values throughout than in the Poisson series for number reported. If true, this is evidence that every tagged fish has as much chance of being caught at any particular time as every other tagged fish.

Of the 14 cases where two or three fish were recovered on the same day, the records indicate that five of these multiple recoveries were also from essentially the same place, that six were possibly from the same place, although the records are too vague to be certain, and that only three were from definitely different places (places more than five miles apart). In other words, between 5 and 11 of the 14 multiple recoveries were made in pairs or triplets from within a 20-square-mile area (a different 20 square miles in each case), although the potential area from which recoveries could be made was some thousands of square miles. Obviously there was a tendency for the fish that were recovered on any given day to be also recovered from the same place. The logical explanation for this phenomenon is that certain individuals tended to remain together for some time. One pair apparently remained together for five years.

In a majority of the cases, tags that were recovered at the same time and place were also from fish that had been tagged within a day or two of one another. This suggests that, throughout the three weeks during which tagged fish were released, a number of distinct schools left the tagging area, so that each school consisted predominantly of the most recently tagged fish. It is also a fact that tags were taken almost simultaneously at widely separated places, which is

evidence that the tagged fish formed several distinct schools of fish as opposed to a single school. The word "school" as used here designates any group of fish which tends to remain together, and by definition such a "school" could consist of as few as two fish. However there is unpublished evidence (Oakland, MS) on file at the Central Fisheries Research Station which indicates that fairly large groups of Lake Winnipeg whitefish–probably at least several hundred–tend to remain closely associated for considerable lengths of time. Presumably therefore, most "schools" are big enough to be considered "schools of fish" in the usual sense of that expression.

The data given above lead to two apparently conflicting conclusions. On the one hand, because the number of tags reported as recovered per day is essentially a Poisson series, all tagged fish are presumed to be uniformly exposed to the probability of capture at any given time. On the other hand, when pairs and triplets of tagged fish were recovered on the same day they were more likely to be from a small part of the population than representative of the population as a whole. A possible explanation of this paradox is as follows: over a period of time each fish has an equal chance of being caught, although on any given day the fishery exploits only relatively few of many schools of fish in the lake.

Table II shows the general relationship between time of tagging and place

TABLE II. The general relationship between date of tagging and place of recovery for all the whitefish that were tagged and released into Lake Winnipeg at Dauphin River in 1938 and recovered during various summer fishing seasons.

Date tagged	Number recaptured			Percentage recaptured of those tagged
	South	North	Total	
Oct. 27–Nov. 1	30	9	39	8.4
Nov. 2–Nov. 8	11	6	17	3.9
Nov. 9–Nov. 14	14	25	39	6.3
Total	55	40	95	6.0

of recapture. The boundary between "south" and "north" was the 53rd parallel of latitude which divides the whitefish area into roughly equal water areas. There was a statistically significant tendency for early-tagged fish to be taken south of the line and for late-tagged fish to be taken north of it. This is further evidence that certain fish (in this case those tagged at about the same time) tended to remain together. The last column in Table II indicates differences between proportions of the number of fish recovered to the respective number tagged. This evidence, such as it is, indicates that some schools were exploited more heavily than others during the five years in question.

Table III indicates the number of tags recovered and reported for each of the five summers. Note that six of the 95 recoveries are not included because the year of recapture was not recorded.

Table I indicates that the total commercial catch of whitefish was approximately the same in each of the years 1940, 1941, 1942 and 1943 and about one-

TABLE III. The time and place of recapture of all the whitefish tagged and released into Lake Winnipeg at Dauphin River in 1938 and recovered during various summer fishing seasons.

Year of recapture	Approximate time at large (*years*)	Number actually recaptured			Expected number recaptured[a]
		South	North	Total	
1939	2/3	0	26	26	45
1940	1 2/3	27	4	31	30
1941	2 2/3	18	2	20	10
1942	3 2/3	2	3	5	3
1943	4 2/3	6	1	7	1

[a]See text for explanation.

half as great in 1939—presumably because less fishing was done that year. If catchability—defined by DeLury (1947) as the proportion of the population captured during a certain time by one unit of fishing effort—had remained constant, the number of tags recovered should have diminished in a more or less regular manner. In addition to the effects of the mortality rate (for the largest whitefish, evidence given below indicates that the mortality rate is 64 per cent, and other whitefish of commercial size presumably do not differ too much from this value), it seems likely that the ratio between number of tags recovered in any one year and the number recovered the previous year would also be diminished by special mortality associated with tagging, and by the loss of tags. It would therefore not be at all unreasonable to assume, for instance that the number of tags available for recovery diminishes by two-thirds each year (it seems unlikely that the true rate is appreciably less though it could be more, which would only strengthen the resulting conclusion). If this rate is assumed, and if the chances of catching a tagged fish in 1939 are assumed to be only one-half as great as in other years because total catch in 1939 was only about one-half as great, then if a total of 89 tags are recorded as recaptured, the numbers expected each year would be those shown in the last column of Table III. It is interesting to note that about "half a fish" would be expected in all the years after 1943, with which expectation the fact that none was actually recorded is in close agreement.

The difference between the number of recoveries observed and the number expected, shown in Table III, is highly significant. Since any other reasonable hypothesis regarding rate of recovery would obviously also indicate a significant difference between observed and expected values, the data show that the average catchability of tagged fish varied from year to year. When those taken in the south half are separated from those taken in the north half (note that the south half is nearer to the place where the tagged fish were released) the variation in catchability becomes even more obvious—catchability at one place was obviously not related to catchability at another.

Evidence that catchability can vary is presented in both Table II (evidence that subsequent catchability varied with time of tagging) and Table III (evidence that catchability varied with the year of recapture and with the general

area of recapture). Therefore, in so far as conclusions based on the rather scanty tagging data are valid, it can be concluded that catchability among Lake Winnipeg commercial whitefish can vary considerably. If catchability can vary then good fishing such as occurred in 1940 and 1941 does not necessarily represent an abundance of fish nor does poor fishing such as occurred in 1936 necessarily represent a dearth.

DISCUSSION OF VARIATION IN CATCHABILITY

It is interesting to speculate on what causes catchability to vary if it does actually vary. An obvious explanation is fluctuations in environmental conditions, particularly water temperatures. Whitefish, in general, tend to avoid warm water, and a few scattered observations on file at the Central Fisheries Research Station indicate that Lake Winnipeg whitefish specifically avoid water that is about 60° F. or warmer (there is an unexplained variation in the exact temperature avoided). Observations made during 1948–52, inclusive, showed little or no difference between surface and bottom water temperatures at any given time and place on the whitefish grounds during the summer fishing season. However, temperature increased with time each year, and there were declines in temperature from south to north and from inshore to offshore. In the few cases where appropriate observations were made, the fishermen found the most fish where they would be expected on the basis of the hypothesis that a gradual movement of the aquatic isotherms with time keeps whitefish concentrated as they move out of the newly warmed water. It could be postulated that similar conditions accounted for the moderate fishing success during 1942–51, inclusive, and that in 1941 and 1942 there was an entirely different situation, with all the lake water warmer than 60° except for the bottom water in the deepest parts. That condition would have concentrated all the whitefish in a relatively small area, and naturally they would have been easy to catch. As far as can be ascertained from enquiry, the exceptional catches of 1940 and 1941 were actually made in the deepest parts of the lake, and no whitefish could be caught elsewhere.

Records kept by the Meteorological Division of the Department of Transport are consistent with the postulated conditions. Interpolation among the published isotherms indicates that in 1940 and in 1941 the average July air temperatures over the whitefish grounds were above normal by 2° and 3° F., respectively, whereas only two other years, 1943 and 1947, subsequently had temperatures above normal. In the City of Winnipeg (the nearest point at which wind velocities were recorded) average July wind velocities in 1940 and in 1941 were less than in any subsequent year. Therefore, as far as can be estimated by extrapolation and interpolation from the records, the conditions were those most likely to produce the hydrographic conditions postulated above for 1940 and 1941 as opposed to those assumed for subsequent years.

Unfortunately, the exact position at which wind was recorded was changed about 1938, and wind velocities before that time are therefore not strictly comparable with those after 1941. Average air temperatures in 1935, 1936 and 1937 were higher than in any other year under consideration, namely 7°, 7° and 6°

above normal, respectively. The poor fishing in these years might therefore be attributed to a complete warming of the whole lake so that, because there was no choice of temperature, the whitefish remained evenly distributed over the whole whitefish area.

SPAWNING RUNS AT DAUPHIN RIVER

The whitefish used in the tagging experiment discussed above were "by-products" of spawn-taking operations at the mouth of the Dauphin River. Fish for spawning were caught at the same place and in the same gear (a pound net that completely blocked the river) from 1932 to 1947. The number taken each year is shown in the fifth column of Table I. The fluctuations in number of these spawners taken are sometimes regarded as corresponding to fluctuations in the abundance of whitefish in Lake Winnipeg. In this connection, note that there is a positive correlation of 0.82 between the values in column 5 and those in column 1 of Table I.

It should be realized that the spawners that enter Dauphin River are an insignificant part of the spawning population. Their behaviour is also atypical in that whitefish normally spawn in lakes, not in rivers. The abundance of spawning fish entering Dauphin River is, therefore, not necessarily an indication of general abundance.

The last column of Table I indicates water levels in Lake Winnipeg during the years under consideration. There is a negative correlation of 0.67 (significantly different from zero) between numbers of spawners taken in the river and October lake levels during 1932–37, inclusive. A logical explanation of the fluctuations is that, when lake levels are low, the current is more perceptible at the river mouth and that for some reason this attracts whitefish which are in the immediate vicinity into the river. That the size of the run is correlated with the size of the catch for the same year is therefore easily accounted for, since water levels are dependent on weather.

AGE STUDIES

Growth Rate

Lengths and weights were recorded only for the years 1944–51, inclusive, so that only readings of scales collected during those years could be used to assess rate of growth. The growth in weight was considered rather than growth in length, because weight is more closely related to biological productivity, because it is the factor in which the fishing industry and fisheries administrators are primarily interested, and because weights are more conveniently tabulated. The length-weight relationship as derived from the data is expressed by the equation:

$$y = 0.00071\, x^{2.96}$$

where y is the weight in pounds and x is the fork length in inches.

As the ages were being determined, the distance between the outermost annulus and the edge of the scale was noted in a few representative scales from the samples for each year. Since scale growth is usually regarded as closely connected with general growth, a comparison of scale measurements among

samples taken on various dates from June to October made it possible to get a rough idea of the annual growth pattern. There seems to be considerable variation from year to year in the amount of growth made by a certain time, but in a typical year the pattern is apparently about as follows. Growth begins toward the end of May or in early June and continues until about the middle of September. Thus there are only about four months of the year during which Lake Winnipeg whitefish grow. About one-half of the growth for the year is made by July 1.

Although samples were taken from fish landed at 14 fishing ports in all, they were taken consistently at only six. In a preliminary analysis, the average size for each age for each year at each port was determined. These data permitted the relative growth rates, as assessed from size at each age at each port, to be compared. Table IV shows the order of growth rate for each year as

TABLE IV. Order of growth rates of Lake Winnipeg whitefish as indicated by samples from six fishing ports. The ports are in order from south to north. A "1" indicates fastest growth for the year, "2" second fastest growth, etc.

Port	1944	1945	1946	1947	1948	1949	1950	1951
Berens R.	1	1	1	4	1	2	2	6
George Is.	5	2	2	3	3	1	5	4
Sandy Is.	2	6	5	1	4	6	3	3
Mukutawa R.	3	5	3	5	6	3	1	1
Spider Is.	4	4	4	2	5	4	4	5
Warrens Ldg.	6	3	..	6	2	5	6	2

assessed on the basis of the preliminary analysis. The lower the number designating order, the faster the growth rate. The ports are arranged in order from south to north, and since fishermen tended to fish in the vicinity of their home port, the place of capture of the fish samples can be regarded as roughly in the same order. The variations from year to year are regarded as sampling error, and on this basis Table IV is interpreted as indicating a gradation from slightly faster growing fish on the more southerly grounds to slightly slower fish on the more northerly. This variation with location is ignored below because it is slight and because roughly equal numbers of fish were taken in the annual samples at each port.

Table V shows the average size at each of the well represented ages each year. There is no evident trend in these values, which indicates that growth rate probably did not change appreciably between 1944 and 1951.

Table VI shows the size distribution at each age for all the samples combined. The table demonstrates that fish of the same age can vary tremendously in size, but this does not obscure a tendency for size to increase with age. A comparison of the size ranges suggests that the younger age-groups are restricted by some limitation on the minimum size that will be recorded. This phenomenon can be attributed partly or wholly to the fact that there is a minimum size of fish which a given gill-net will take in any quantity. In other words there is an

TABLE V. The relationship between age and average weight in samples taken from catches of Lake Winnipeg whitefish during various summer seasons. Only averages based on 20 or more fish are shown.

	Age in years					
	4	5	6	7	8	9
1944	..	2.4	2.4	2.7	2.9	..
1945	..	2.3	2.5	2.6	3.0	3.4
1946	..	2.1	2.4	2.8	3.0	3.2
1947	..	2.5	2.6	2.8	3.1	3.5
1948	2.1	2.6	2.8	3.0	3.1	3.5
1949	2.1	2.2	2.6	2.8	2.8	..
1950	2.0	2.3	2.6	2.8	..	..
1951	2.1	2.4	2.6	2.7	..	..

TABLE VI. The number of fish of a given age which are of a given weight in all samples taken from commercial catches of Lake Winnipeg whitefish during the summer fishing seasons of 1944–51, inclusive.

Wt. in lbs.	Age in years														
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
¾	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..
1	1	2	1	..	..	..	..	..	..	..	..	..	..	..	..
1¼	0	16	17	7	1	1	..	..	..	..	..	..	..	..	..
1½	2	35	31	25	16	2	..	..	..	..	..	..	..	..	..
1¾	0	71	116	60	25	4	1	..	..	..	..	..	..	..	..
2	1	148	293	214	87	28	8	3	..	..	..	..	..	..	..
2¼	0	123	460	413	170	37	13	5	2	..	..	..	..	..	..
2½	1	72	422	468	248	93	16	5	4	..	..	..	..	..	..
2¾	..	29	238	353	241	73	15	5	1	1	..	..	..	..	..
3	..	8	149	282	197	86	23	4	1	0	..	..	..	1	..
3¼	..	4	47	139	134	64	16	9	2	0	..	..	..	..	..
3½	..	..	15	78	81	44	22	1	5	2	..	..	..	..	..
3¾	..	..	6	20	36	27	12	5	0	2	..	..	..	..	..
4	..	..	5	10	23	18	15	1	3	3	..	..	..	..	..
4¼	..	..	1	5	13	9	5	4	5	0	1	..	..	..	..
4½	..	..	..	2	5	10	7	3	0	0	0	..	..	..	..
4¾	..	..	..	0	5	7	5	0	0	0	0	..	..	..	..
5	..	..	..	1	2	6	5	0	1	0	0	..	..	..	..
5¼	..	..	..	1	1	3	3	2	0	0	0	..	..	..	..
5½	..	..	..	..	1	0	2	1	1	0	0	..	..	..	..
5¾	..	..	..	..	..	0	2	1	1	0	0	..	..	..	..
6	..	..	..	..	..	0	0	1	3	0	0	..	..	..	..
6¼	..	..	..	..	..	0	2	1	0	1	0	1	..	..	..
6½	..	..	..	..	..	0	1	1	0	0	0	..	..	..	..
6¾	..	..	..	..	..	1	0	0	0	0	0	..	..	..	..
7	..	..	..	..	..	..	1	1	1	0	0	..	..	..	..
7¼	..	..	..	..	..	..	..	..	..	0	0	..	..	..	..
7½	..	..	..	..	..	..	..	..	..	1	0	..	..	..	..
7¾	..	..	..	..	..	..	..	..	..	..	0	..	..	..	..
8	..	..	..	..	..	..	..	..	..	..	1	..	2	..	..
8¼	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1

indication of net selection in the catches of younger fish (say less than 8 years old).

The points plotted in Figure 2 are based on average values calculated from the weights given in Table VI. The only averages used are those based on cases

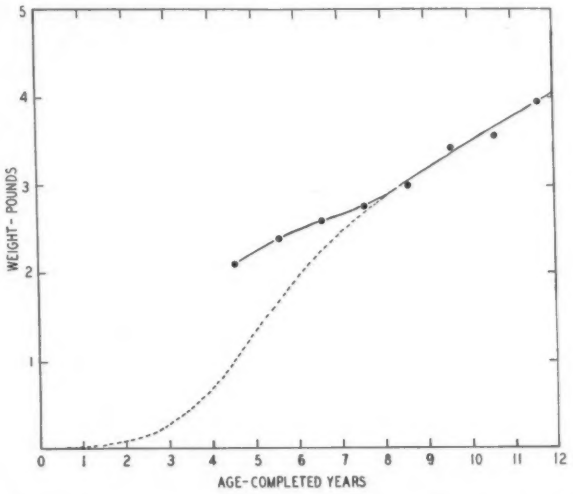

FIGURE 2. Growth curve for Lake Winnipeg whitefish. Solid line represents relationship between average weight and average age of fish caught. Only averages based on more than 20 fish are used. Broken line represents approximately probable relationship if net selection could be eliminated.

where at least 20 fish of the same age were weighed. The points are plotted at ages 4.6, 5.6, etc. because at the average time of capture the fish in the samples were presumed to have made about 60 per cent of their growth for the year. The solid line represents a growth curve that ignores the effects of net selection. If truly representative samples (i.e. samples unaffected by net selection) had been available, probably the growth curve for fish less than eight years old would have been something like the broken line in Figure 2. The broken line is only meant to be a very rough approximation to the true growth curve. It is based on the following considerations:

1. Net selection presumably produces samples in which the average weight of all fish less than 8 years old is greater than the corresponding average weight in the population, and the younger the fish, the more divergent is the sample from the population in this respect.

2. In general, growth curves of organisms are sigmoid curves.

3. General observations (unpublished) indicate that in Western Canada young whitefish weigh roughly 0.1 pounds when 1½ years old and roughly 0.2 pounds when 2½ years old.

Mortality Rate

The mortality rates that prevail in a population of fish can be estimated if the ages of individual fish in a large random sample are known. The technique has been reviewed by Ricker (1948). The underlying principle is as follows. When those fish are disregarded which are too small to be taken with full efficiency by the particular gear used, then generally the number of fish of each age is less than the number one year younger (this is not true where there are violent fluctuations in year-class strength). The obvious explanation is that the number of fish in any year-class diminishes from year to year as a result of deaths from various causes. The observed rate of decrease within the sample is regarded as representing the annual mortality rate in the population, i.e. the proportion of fish which die each year. In practice mortality rates are determined graphically from "catch curves". Catch curves are derived by plotting the logarithm of the number of fish of a given age against their age.

Table VII, which shows the number of fish of each age in the annual samples, is the appropriate raw material for constructing catch curves for the years under consideration. In Table VII variation from place to place in any year is disregarded for reasons given in the preceding section. Figure 3A shows a catch curve based on the 1944 data from Table VII. The ascending left limb and dome of the catch curve presumably represent year-classes of fish which were not fully vulnerable to the fishing gear. The descending right limb presumably represents year-classes that were fully vulnerable to the gear and whose numbers in each case were less than the number in the preceding year-class because some died (were killed) each year. The points on the right limb could be regarded as falling very nearly along a straight line, from which deviations represent the effect of inadequate numbers in the sample. If the best straight line were drawn through the points, then using the techniques outlined by Ricker, the slope of that straight line could be used to calculate average mortality rate among the fully exploited year-classes. The annual mortality rate so calculated is 67 per cent, which means that out of every 100 fish big enough to be fully exploited by the gear at a given time, 67 would die leaving 33 survivors exactly one year later.

With the possible exception of 1949, the data in Table VII would yield similar catch curves for each of the years 1944–51, and each would be a good approximation to a straight line in the right limb. The respective calculated annual mortality rates from 1945 to 1951, inclusive, would be 75 per cent, 71 per cent, 64 per cent, 63 per cent, 50 per cent, 66 per cent and 77 per cent. On the other hand, with the possible exception of 1937, for which the mortality rate would be 62 per cent, the samples representing 1937–43, inclusive, would yield erratic catch curves—possibly as a result of non-representative sampling—although they would give no evidence of a trend in mortality rates. There was in fact, no evident trend in whitefish mortality rate over the period 1937–51—the apparent changes in calculated annual mortality rates from year to year are regarded as normal variation. Had fish actually been scarce in 1936, unusually plentiful in 1940 and 1941, and scarce after 1942, there would necessarily have been quite noticeable changes in mortality rate. The fact that there were no such

TABLE VII. The number of fish of each age in samples taken from commercial catches of Lake Winnipeg whitefish.

	Age in years																	
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
1937	1	189	735	190	79	43	21	4	2	4	..	2	..	..	..	..	..	1270
1938	..	31	1622	487	84	66	50	29	10	7	3	..	1	1	..	..	1	2392
1939	98	119	182	296	23	12	14	6	13	2	1	1	..	..	..	..	..	767
1940	..	24	96	151	188	44	12	7	9	8	5	2	3	..	1	1	..	551
1941	2	22	176	128	40	22	..	..	..	..	..	..	..	..	..	..	..	390
1942	..	9	74	212	111	103	38	2	..	..	..	..	1	..	..	..	..	550
1943	..	37	177	151	101	72	37	7	4	1	1	..	..	..	..	..	..	589
1944	..	19	330	401	156	45	16	4	6	3	..	..	1	1	..	..	..	982
1945	..	3	42	267	322	114	21	8	1	..	1	..	..	..	..	..	..	779
1946	1	18	79	143	235	145	39	9	5	1	..	..	..	..	..	..	..	675
1947	..	19	157	287	202	96	36	10	4	2	..	1	1	.	..	..	..	815
1948	..	33	335	507	190	59	41	9	4	1	..	..	..	..	1	..	..	1180
1949	2	225	172	130	77	26	14	10	5	2	..	..	..	..	..	..	..	663
1950	1	114	409	151	72	19	5	3	3	1	1	..	..	..	..	..	..	779
1951	1	78	277	192	32	9	2	..	2	..	..	..	..	..	..	..	..	593

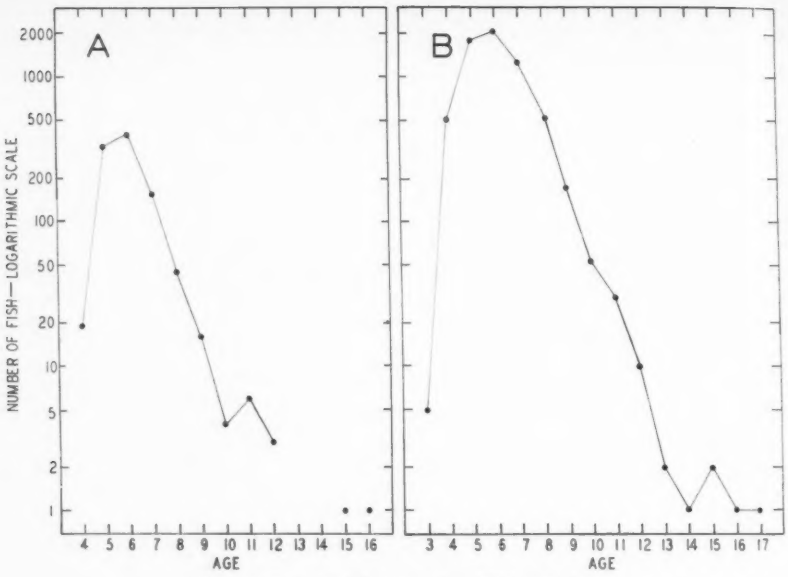

FIGURE 3. A. Catch curve for 1944 sample.
B. Catch curve for combined 1944 to 1951 samples.

changes indicates that the observed fluctuations in fish catches were not related to abundance.

The data for the period 1944–51 were grouped together and used to plot the composite catch curve shown in Figure 3B. The points on the right limb of this curve can be regarded as falling along a straight line from which they deviate only because of the vagaries of sampling. The slope of the best straight line would indicate an average annual mortality rate of 64 per cent for the fully exploited year-classes (ages 8–14, inclusive). The value 64 per cent is an estimate of the general annual mortality rate which prevailed over the whole period of time under consideration. Ricker (1947) calculated a similar mortality rate for Lake Opeongo whitefish and lower rates for those from Lake Nipigon and Shakespeare Island Lake—all based on relatively small samples.

It is interesting to note that Kennedy (1953) estimated that the mortality rate among unexploited Great Slave Lake whitefish was 61 per cent. The negligible difference between the two mortality rates suggests that perhaps the present commercial fishery on Lake Winnipeg has very little effect on the mortality rate of the whitefish. Presumably fishermen catch only a relatively small part of the fish present and most whitefish die from natural causes.

YEAR-CLASS FREQUENCY

The fluctuations in Lake Winnipeg whitefish catches have generally been attributed to fluctuations in the abundance of commercial fish in the lake. The poor catches in 1936 were attributed to a dearth of fish at that time, and it was

generally said that the lake was "fished out". The remarkable catches of 1940 and 1941 were attributed to an abundance of fish and it was generally conceded that the lake had recovered from previous overfishing. The decline after 1941 was attributed to a decrease in abundance of fish as the result of fishing. Such a drastic increase in abundance as is popularly believed to have occurred between 1936 and 1940 could only have occurred if one or more year-classes which were much stronger than average had appeared in the 1940 catch for the first time. The time involved is too short to indicate a gradual increase in the strength of all the year-classes involved in the fishery. The data shown in Table VII can shed considerable light on this situation. On the basis of Table VII the proportion that fish of each age formed of the total sample for the year was calculated and was used to plot Figure 4. Since the frequencies are expressed to the nearest whole number, ages represented by less than 0.5 per cent of the total do not register. A study of Figure 4 indicates that the phenomenal catches of 1940 and 1941 cannot be attributed to one or more strong year-classes, nor can the poor fishing of 1936 be attributed to a series of weak year-classes. The 1933 year-class which was the strongest component in the 1940 sample was also the "dominant year-class" in the 1938 and 1939 samples. If the 1933 year-class had been particularly abundant, then the catches in 1938 and 1939 should have been much better than they were. Also the 1933 year-class contributed little to the 1941 sample. To the extent that the samples can be regarded as representing the populations, it appears that the phenomenal catches of 1940 were not primarily the result of a particularly strong year-class entering the fishery that year. Further, the 1936 year-class, which was "dominant" in the 1941 sample, did not appear to be particularly strong after 1942. Therefore, it seems unlikely that the 1936 year-class was strong enough to account for the phenomenal catches in 1941. Finally, if the poor catches in 1936 were the result of a dearth of fish, then the 1931, 1930 and 1929 year-classes (respectively 5+, 6+ and 7+ years old in 1936) should have been particularly weak. Since these year-classes were represented in the samples every year until 1940, none of them can be regarded as particularly weak, and on the basis of the data the poor catches of 1936 cannot be attributed to a lack of fish in the lake.

Since there was a possibility that variation in annual catch might mask some important factor connected with year-class strength, Figure 5 was also prepared. The values in Figure 5 were derived by multiplying the percentages used in Figure 4 by the respective annual catches shown in the first column of Table I. This gave the approximate quantity of fish of each age caught during those years. These amounts represent relative numbers. Strictly speaking, therefore, the ordinates in Figure 5 are not exactly millions of pounds as is designated, since that would imply an assumption that average weight is the same at all ages. However, it seems likely that this error is small in comparison with errors introduced by assuming that the samples are strictly representative of the whole catch and by the assumption that the recorded statistics represent actual catch, so no attempt has been made to further refine the calculations by considering average size at each age.

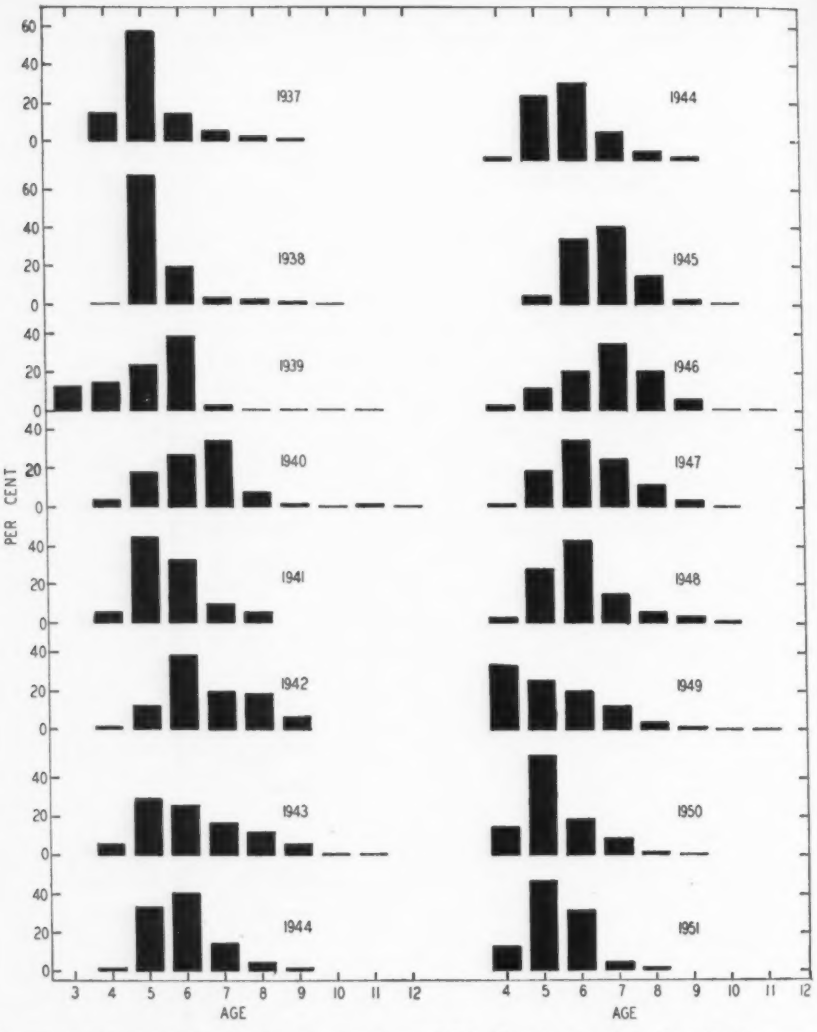

FIGURE 4. Frequency distribution in percentage of fish of each age. Note that the frequency distribution for the 1944 sample is repeated to facilitate comparisons.

If Figure 5 is taken at face value, the line of reasoning used in connection with Figure 4 leads to the same conclusion, that the unusually good fishing of 1940 and 1941 was not the result of an unusually strong year-class nor was the poor fishing of 1936 the result of weaker than usual year-classes. Even though the calculated values given in Figure 5 probably diverge considerably from the actual situation, it seems unlikely that they diverge enough to invalidate this conclusion.

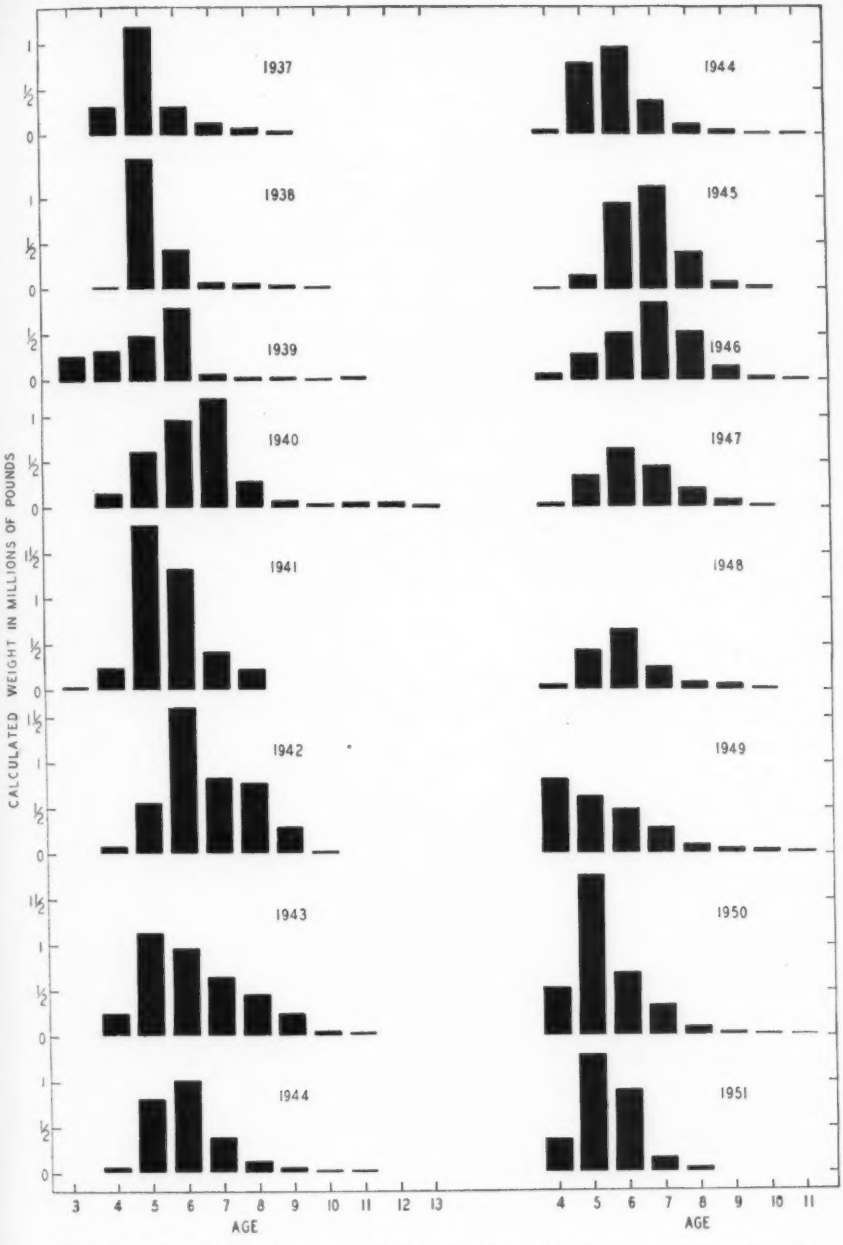

FIGURE 5. The calculated amount of fish of each age in the reported annual catches—see text for explanation. Note that the histogram for the 1944 sample is repeated to facilitate comparisons.

It is interesting to explore the question of year-class strength further. Values for the total contribution that each year-class eventually makes to the commercial catch can be calculated by summing "diagonally" the values used in Figure 5. For instance, the value for the eventual contribution of the 1936 year-class is the sum of the calculated catch of age-3 fish in 1939, of age-4 fish in 1940, age-5 fish in 1941 and so on. (It should be noted that this summation more or less eliminates the error introduced above by assuming that the fish weigh the same at all ages). The lower panel of Figure 6 shows the magnitude of these values for the years 1932–45, inclusive. For the year-classes 1932, 1933 and 1941–45, inclusive, the data in Figure 5 were not extensive enough to include all the presumed contributions. In those cases the unknown contribution is estimated to be the average of the contributions made by other year-classes when they were the ages in question. In no case was the estimated unknown contribution greater than 20 per cent of the total.

The lower panel of Figure 6 seems to indicate that the year-classes 1932–39, inclusive, were of approximately equal strength, that the year-classes 1940–44 were about one-half as strong, and that the year-class 1945 was about as strong as the 1932–39 year-classes.

The upper panel in Figure 6 shows the recorded annual catches of fish when the respective year-class in the lower panel was spawned. For example, the year-class 1932 resulted from eggs spawned in 1931, and the corresponding

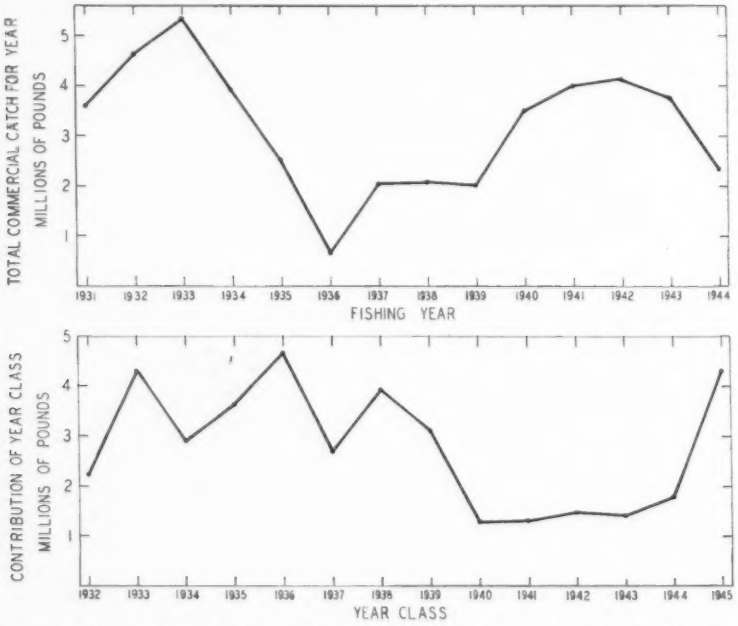

FIGURE 6. Calculated strength of year-classes and assumed relative abundance of their parents (see text for explanation).

value in the upper panel is the recorded quantity of adult fish caught from April 1, 1931, to March 30, 1932. The values in the upper panel might therefore be regarded as representing the relative abundance of the parents of the respective year-classes shown in the lower panel. Comparison of the two panels indicates no relationship between the presumed relative abundance of the parents and the calculated contribution that the resulting offspring eventually make to the catch. There are three possible explanations: (1) the number of offspring may not depend on the number of parents nearly as much as it depends on other factors; (2) catch may not reflect relative abundance; or (3) the calculated values for year-class strengths may be in error (as will be shown below, explanation (3) is probably essentially the same as explanation (2)).

Catch curves can also supply pertinent information on relative year-class strength. The points plotted in Figure 7 are based on Table VII. The actual catch curves are not shown; instead the best straight line is drawn through those points which would form the respective right limbs of the catch curves. Note that values for less than four fish are not shown and that years previous to 1944 are

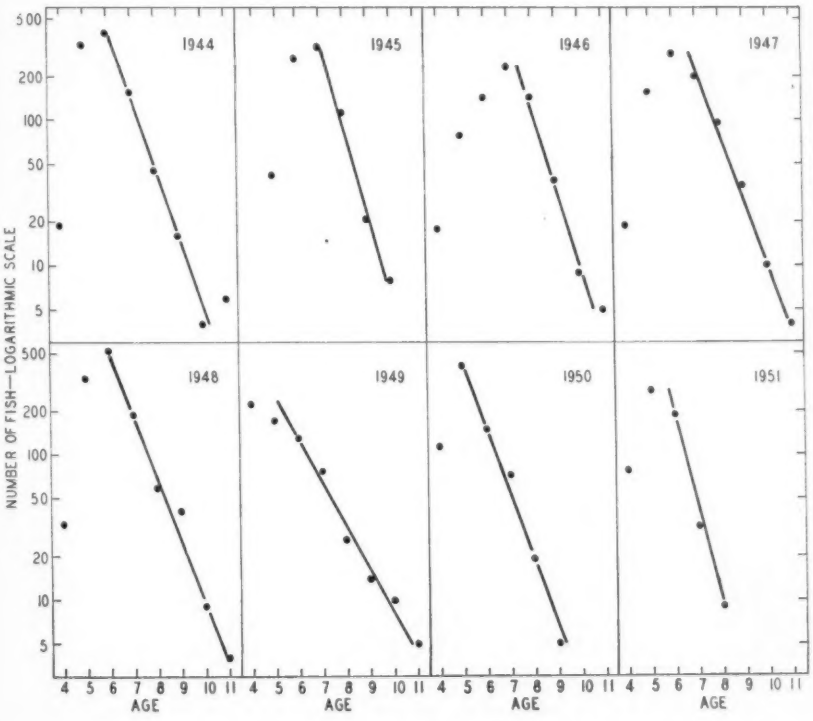

FIGURE 7. Points on the catch curves for 1944–51, inclusive, and the best straight line through their right limbs. Only points representing at least four fish are shown.

TABLE VIII. The percentage difference between the number of fish of each age plotted in Figure 7 and the "expected" number represented by the corresponding line where position above or below the line is represented respectively by "+" and "−". Only fish at least 7 years old are considered.

Year of capture	Year-class								
	1935	1936	1937	1938	1939	1940	1941	1942	1943
1944	0	−8	+5	..	..	..	..	..	..
1945	+23	−13	+21	−16	..	..	..	..	..
1946	+51	−18	+5	+17	−44	..	..	..	..
1947	..	+11	−2	+26	+18	−10	..	..	..
1948	..	..	+11	−2	+54	−15	+2	..	..
1949	..	..	..	+20	+20	−14	−27	+18	..
1950	..	..	..	..	..	..	−24	0	+31
1951	..	..	..	..	..	..	..	..	+4
Average	+25	−7	+8	+9	+12	−13	−16	+9	+18

disregarded because the values are too erratic, presumably because the samples are not representative of the populations. Obviously a point that falls above its respective line suggests a stronger than average year-class, whereas a point that falls below suggests one that is weaker than average.

Evaluations of the relative strengths of year-classes as represented by each of the samples considered are shown in Table VIII. The values indicate the percentage that the difference between the number of fish represented by a point and the number "expected" on the basis of the position of the line is of the number "expected". Only fish at least seven years old are included, since there is evidence that they must be that old before they are fully vulnerable to the fishing gear. Only year-classes that are represented in two or more samples are included.

The outstanding features of Table VIII are the variation in the values representing relative strengths of the year-classes as assessed from various samples, and the moderate values for average departure of points from their respective lines. Apparently there is very little, if any, difference in relative strength among the year-classes considered.

With this information Figure 6 can be re-examined. If it is assumed that year-classes are of approximately equal strength and also that the abundance of fish is only a minor factor in determining annual catch, then the variations in ultimate contribution of the year-classes as shown by the lower panel of Figure 6 could be explained as follows. The year-class 1932 made an average contribution because only a moderate production of fish was possible during 1947 when it was the predominant year-class in the catch as indicated by the sample taken that year. The year-classes 1933–37, inclusive, made larger than average contributions since the conditions needed to produce a good catch prevailed during the years 1940–43 when they were predominant in the respective catches. The year-classes 1938 and 1939 were larger than average contributors since they each formed a large part of the catch during three successive years when fishing was

moderate to good. The year-classes 1940 and 1941 made smaller than average contributions because they were predominant in the catches of 1947 and 1948, respectively, when only a low production of fish was possible. The year-classes 1943 and 1944 made smaller than average contributions because these year-classes were never a predominant part of the catch in any year. The year-class 1945 made a larger than average contribution since it happened to form a large part of the catch in each of three successive years when moderate to good production was possible. Thus the lower panel of Figure 6 can be readily explained on the basis of a reasonable hypothesis which assumes no variation in year-class strength.

It was concluded earlier that Figures 4 and 5 do not show *violent* fluctuations in year-class strength such as would account for a tremendous abundance of whitefish in 1940 and 1941 or a dearth in 1936. In view of the conclusion, as a result of examining catch curves, that there has been little if any variation, Figures 4 and 5 can be re-examined. It will be noted that the year-class 1933 was the dominant year-class as 5-year-olds in 1938, as 6-year-olds in 1939 and as 7-year-olds in 1940, and the year-class 1938 was the dominant year-class as 5-year-olds in 1933, as 6-year-olds in 1934 and as 7-year-olds in 1935. Because each dominated the catches for three successive years, they could conceivably be regarded as strong year-classes. However, since the 1933 year-class failed to produce good fishing in 1938 the possibility that it was a stronger than usual year-class seems remote. (It will be noted in Figure 7 on the catch curve for 1944 that the point representing the 1933 year-class is well above the line, which signifies a strong year-class, but because the corresponding point on the 1943 catch curve would be below its line no significance is attached to this fact.) Table VIII indicates that the 1938 year-class was not particularly strong either.

There is an alternative explanation for what at first glance appear to be classes moving through the fishery from time to time. The fishery can be regarded as tending to take mostly fish that are 5 and 6 years old, and the samples can be regarded as small enough that they vary considerably in composition through chance alone. These circumstances would permit the dominant year-class in the sample for any given year to be anything from 4- to 7-year-old fish purely by chance. Under this hypothesis the question of whether a particular year-class forms a major part of the catch in two, three or even four consecutive years is dependent wholly on the vagaries of sampling.

The extent to which year-classes of Lake Winnipeg whitefish differ in strength cannot be accurately assessed on the basis of available data. However, there is probably more justification for concluding that there is comparatively little variation in year-class strength than there is for concluding otherwise.

SUMMARY

1. The results are based on the tagging of 2,003 whitefish in 1938 of which 126 were recovered, and on the determination of the ages of 12,975 whitefish collected each year from 1937 to 1951, inclusive.

2. During the past 20 years the ease with which Lake Winnipeg whitefish

could be caught has fluctuated violently, with good fishing in the early 1930's, poor fishing in 1936, good fishing in 1940 and 1941, and mediocre fishing since. These fluctuations are usually attributed to fluctuations in the general abundance of whitefish.

3. The tagged fish showed evidence of a tendency to remain together for as much as five years.

4. The pattern of tagging recoveries indicates that catchability (the proportion of the population captured during a given time by one unit of fishing effort) can vary considerably.

5. Variations in catchability from year to year can be easily explained on the basis of variations in weather conditions. Presumably light winds and above-average air temperatures in July are the conditions needed for maximum catchability.

6. Data on growth rate are presented.

7. Total annual mortality rate remained relatively constant at about 64 per cent for all fully exploited year-classes over the period considered.

8. The various year classes were probably of about equal strength; and certainly the best fishing in recent years cannot be attributed to strong year-classes, nor can the worst fishing be attributed to weak year-classes.

CONCLUSIONS

In view of deficiencies in the data, it would be unwise to rely heavily on any conclusions to be drawn from them. However, there are good grounds for doubting the commonly accepted idea that fluctuations in fishing success (availability) for Lake Winnipeg whitefish over approximately the past 20 years was caused by corresponding fluctuations in the abundance of fish. Specifically, on the basis of the available data the grounds are:

1. Catchability can vary—a plausible explanation is variations in weather conditions.

2. Growth rate has remained essentially unchanged (an abundance of fish often causes slow growth and vice versa).

3. According to Table VII average size has probably not changed appreciably (a decrease in abundance would necessarily mean smaller fish in the catch, because obviously fish just big enough to be caught would make up a larger proportion).

4. Annual mortality rates among fully exploited fish remained essentially unchanged (this evidence would be particularly hard to reconcile with the idea of fluctations in abundance).

5. The best fishing could not be attributed to one or more strong year-classes nor could the worst fishing be attributed to a series of weak year-classes and in fact all the year-classes were of approximately equal strength.

The author knows of only one piece of contrary evidence, namely that the abundance of spawning fish at Dauphin River was related to fishing success. As shown above, there is another equally logical explanation of this phenomenon.

Therefore, although the data do not permit clear-cut conclusions, they do indicate a greater likelihood that the quantity of Lake Winnipeg whitefish of commercial size has remained relatively constant for about twenty years than that it has fluctuated considerably during that time.

The fact that the combined fishing and natural mortality rate among fully exploited Lake Winnipeg whitefish appears to be only slightly greater than the natural mortality rate alone among comparable Great Slave Lake whitefish, suggests the possibility that fishing mortality is negligible among Lake Winnipeg whitefish. If true, this means that they could be exploited more heavily than they are without depleting the lake. Of course the evidence is at present insufficient to warrant a recommendation that the rate of exploitation be allowed to increase, nevertheless it is strong enough to indicate that a further investigation of this possibility is highly desirable.

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Some Aspects of Olfactory Perception in Migrating Adult Coho and Spring Salmon[1]

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ABSTRACT

A series of tests were conducted to investigate the sense of smell in migrating coho (*Oncorhynchus kisutch*) and spring salmon (*O. tshawytscha*). By pouring dilute solutions of each of 54 substances into the path of the salmon moving up a fish ladder at Stamp Falls, B.C., positive responses were noted by recording changes in the rate of migration. Representative samples of alcohols, aldehydes, ketones, esters, organic acids and oils, as well as shark repellent and a pulp-mill effluent caused no significant change in the migration. However, dilute water rinses of mammalian skins had distinct repellent action. An acute olfactory sense enabling adult Pacific salmon to detect predators from a downstream position was considered to have survival value. The use of mammalian predator skins to repel salmon from destructive river locations is suggested.

INTRODUCTION

Information on the relation of fish to their environment as perceived through the sense of smell points with increasing emphasis to the use of this organ as a major receptor in directing many activities of fish. Parker (1910, 1911) demonstrated experimentally that catfish (*Ameiurus*) and killifish (*Fundulus*) can detect the presence of food in cheesecloth sacs solely by the sense of smell. Alarm reactions in schools of the minnow (*Phoxinus laevis*) were shown by von Frisch (1941) to occur in the presence of an injured minnow. Repulsion of the fish was traced to a substance given off by broken skin, being effective at dilutions of at least two parts per million. Hasler and Wisby (1951) have suggested that "homing" to a parent stream in salmon may be attributed to discrimination of stream odours. By using the method of conditioned responses, bluntnose minnows (*Hyborhynchus notatus*) were successfully trained to distinguish between chemical differences of two Wisconsin creeks. Preliminary experiments also indicated that the same ability characterizes young Pacific salmon (*Oncorhynchus*).

Evidence of a fine olfactory sensitivity among adult Pacific salmon was discovered by Brett and MacKinnon (1952) when extremely dilute odours from human skin produced a marked decrease in the rate of upstream migration of coho (*Oncorhynchus kisutch*) and spring salmon (*O. tshawytscha*). This finding, and the possibility of discovering attracting odours useful in directing the movement of salmon for conservation purposes, encouraged further research on olfactory perception of migrating salmon.

It cannot be stated unequivocally that detection was mediated through the sense of smell only, since no experiments were performed to eliminate the possibility of taste or the common chemical sense. However, the work of Parker (1912) and the studies of Hiatt *et al.* (1953) would suggest that the very low threshold of stimulation involved would make any other conclusion unlikely.

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MATERIALS AND METHODS

During the course of the 1952 migration of coho and spring salmon up the Stamp River, B.C., 54 substances were tested for their effect on the migration and general behaviour of the salmon. At the point of observation and where experiments were conducted, a concrete fish ladder bypasses an almost impassable falls and allows upstream migrating salmon to proceed over a 25-foot elevation in a series of 13 steps. Approximately 28 cubic feet per second of water flows through the notches from the resting pools of each step (150 sq. ft.). During the fall coho and spring salmon can be seen moving steadily up the ladder in a sequence of jumps or swimming bursts (Figure 1). These fish were counted from early morning until late evening throughout the period September 16 to October

FIGURE 1. An observer counting coho and spring salmon ascending the Stamp Falls fish ladder. A coho salmon can be seen completing a jump from the twelfth to the thirteenth pool. The top of the falls appears in the left background.

3. Records were kept of the number of fish passing a given point in the ladder during successive five-minute intervals. When the rate of migration had "levelled off" (between 9:00 and 10:00 a.m.) from its usual morning increase, an odorous solution was added to the water one step upstream from the point of enumeration. One-half hour later a second solution was tested, and this procedure was continued throughout the day until the migration began its evening decline. The

effect of an odour on the fish was reflected by a significant change in the magnitude of the counts. Since the fish were easily seen in the resting pool adjacent to the observation point, qualitative observations of their response to odours supplemented quantitative records.

Control tests were interspersed between standard tests, using a similar procedure but merely omitting the addition of any compound to the water sample. If any response was apparent or confirmation desired, repetitions were performed.

The following is a list of the substances tested:

1. anise oil*
2. "Vico" trout lure oil*
3. herring oil
4. spermacetti (whale oil)
5. cedar wood oil*
6. cedar leaf oil
7. pine oil
8. eucalyptus oil
9. juniper oil
10. clove oil
11. salmon ova*
12. salmon testis
13. salmon ova-testis mixture
14. salmon milt
15. salmon blood
16. salmon skin
17. young salmon aquarium water
18. ammonium hydroxide
19. urea
20. methylamine
21. trimethylamine*
22. Brasso*
23. Silvo*
24. formalin
25. pulp-mill effluent*
26. shark repellent*
27. human hand*
28. bear paws*
29. deer feet*
30. sea-lion meat*
31. hair seal water rinse*
32. dog*
33. sebacic acid
34. lactic acid
35. soap
36. lanolin*
37. acetic acid
38. caprylic acid
39. amyl alcohol
40. acetaldehyde
41. butyl acetate
42. ethyl laurate
43. ethyl levulinate
44. isoeugenol
45. cholesterol
46. analine*
47. nitrobenzene
48. naptha (gasoline)
49. napthalamine
50. piperidine
51. pyridine
52. phenol
53. orthochlorophenol*
54. sodium sulphate

*Repeated

The substances were chosen for a variety of reasons:

(1) The oils (1–10) because of reports that anise oil and "Vico" trout lure oil attract sport fish, and the possibility that some of the other oil odours might be attractants in the marine or freshwater environments, e.g., herring oil and cedar oil.

(2) Fish products (11–21) since the presence of fish in a stream has been suggested to influence the entry of other fish (White, 1934). The compounds numbered 18 to 21 were included because of their resemblance to the excretory products of nitrogen metabolism.

(3) Brasso and Silvo since they are widely used by salmon troll fishermen to clean and shine their spoons.

(4) Formalin because of its possibility as a preservative for salmon and trout bait.
(5) Pulp-mill effluent because a large pulp mill discharges its wastes into the estuary eight miles below the falls on the Stamp River.
(6) Shark repellent because of its reported effect on sharks (Fogelberg, 1944).
(7) Mammalian odours (27–32) because of the repellent effect of the human hand rinses and the fact that these mammals, with the exception of the deer and possibly the dog, are known predators of salmon.
(8) Substances numbered 33 to 36 were chosen for their possible association with human skin substances. Sebacic acid and lactic acid are present in the sebaceous glands, soap is frequently found in the sweat ducts, and lanolin is the sheep's counterpart of human sebum.
(9) The remainder (37–54) were selected chiefly for their characteristic odour. Attempts were made to choose representatives from a variety of chemical classes, e.g., acids, aldehydes, esters.

The concentration of the dilutions to be tested varied somewhat owing to the physical properties of the various substances. Those substances in the liquid state were diluted to approximately 1 part in 2,000 parts of river water (10 drops per litre), whereas those in the solid state were used at the concentration produced by approximately 3 grams (1 teaspoon) per litre. Repetitions, when carried out, were done with triple concentrations. Dilutions of mammalian and fish tissue slices were made by rinsing or soaking the tissue in one litre of water for one minute. The water from an aquarium containing young salmon, and the water that had been obtained from a tank with young seals, was used undiluted. In the case of the pulp-mill effluent, 200 cc. and 19 litres undiluted were tested in addition to a 250 cc. per litre dilution. The ova from one fish and the testis from another were enclosed in a marquisette bag and immersed in the top pool of the ladder.

Some of the fresh samples were collected two to ten months before the experiment and quick-frozen. These included ova, testes, milt, "seal water", sea-lion meat, bear paws, and deer feet. Particular caution was exercised at all times to avoid contamination from the experimenter's hands or from previously tested substances. Rubber gloves were worn and rinsed in river water before each preparation. A new sterile "sealright" wax container was employed for each solution and fresh medicine droppers or sterile papers were used to handle each chemical. The dilutions were added to the stream through a hole punctured in the bottom of each waxed container and took approximately five minutes to empty into the 28 cu. ft. per sec. of water flowing through the ladder. When mixed this would result in an approximate dilution of 0.002 p.p.m. for the liquids and 0.012 p.p.m. for the solids (water soluble). Several control tests, using river water alone, were conducted to detect possible contamination from the container. An additional test, using rubber gloves as the test substance, was also carried out, all with negative results.

It was decided that the main portion of the experiment should not commence until the "run" had built up to a mean rate of 80 fish per hour. Below this rate

fluctuations were sufficient to make the appraisal of a test difficult. The early period of the run is characterized by a relatively immature stock of fish providing a stream that is consequently low in quantity of gonad discharge, possibly capable of causing attraction (cf. White, 1934). For this reason part of the first seven days of the experiment was devoted to testing a group of potentially attracting substances. This group included ova, testes, ova-testes mixture, milt, and anise oil. Anise oil was later repeated.

Simultaneous counts of fish migrating, and measurement of light intensity, water level, and water temperature were recorded throughout a 24-hour period, October 1–2 (MacKinnon and Brett, 1953). Additional tests with pulp-mill effluent were done three weeks later; and shark repellent, not available during the Stamp Falls migration, was tested on the coho migration at Skutz Falls on the Cowichan River six weeks later.

ANALYSIS OF DATA

The recording of a significant change in the rate of upstream movement of the salmon offered a good measure of perception in quantitative terms. However, the migration was not a consistent one at best. Throughout the course of a day the run varied from one or two peaks during daylight hours to practically zero at night (Figure 2). Superimposed on this gross fluctuation was a variability as a result of chance and unknown factors, not excluding unknown odours of a wide

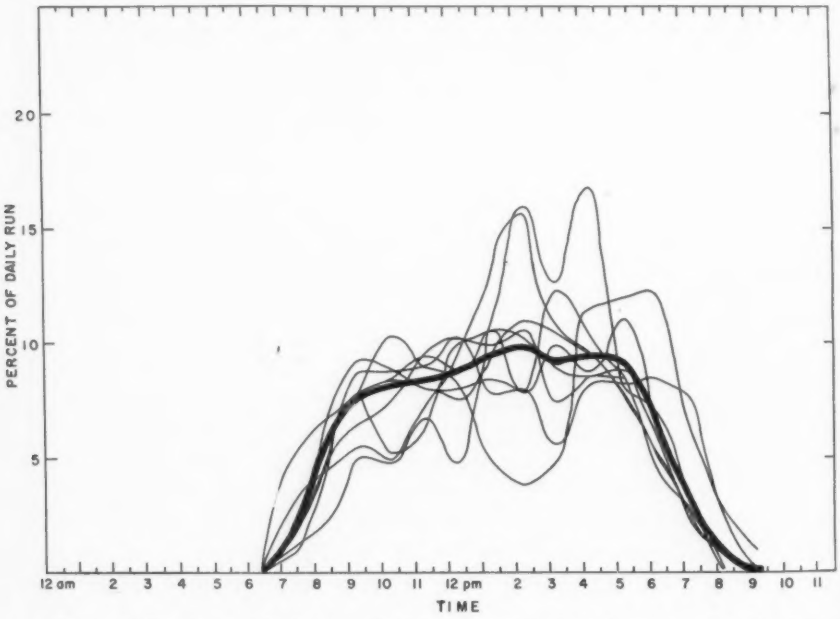

FIGURE 2. Hourly rate of migration of adult coho and spring salmon ascending the Stamp Falls fish ladder. Light lines indicate daily trends; heavy line is the mean rate. Data taken from nine days scattered throughout the migration period on which no odours were tested.

variety which must be constantly washing the olfactory sacs of the salmon. Since the odours and control samples were added on the half-hour, the count for an interval of 15 minutes following the addition was allocated to describing the "influenced" rate of migration, whereas that for the preceding 15 minutes was used to describe the "normal" rate of migration. The mean rate and standard deviation of the "normal" rates were established for each day. If the "influenced" count fell outside two standard deviations of the mean of the "normal" counts it was considered to be significantly different ($P = .05$) and indicative of reaction to the odour.

RESULTS

Of the 54 odours tested, only the odours from human skin, bear paw, deer foot, dog paw, and sea-lion meat produced a significant change in the migration rate. The response to these odours was marked and consistent. It was characterized by a complete halt to upstream movement for at least five minutes. During this time the fish displayed an "alarm reaction" which was seen as a series of rapid swimming movements back, forth, and across the pools of the ladder. An occasional fish leaped back into the next lower pool. The following five-minute period was characterized by an "alertness" on the part of the fish; they remained back against the lower wall of the pool and responded vigorously to slight stimuli such as ripples and floating leaves which under normal conditions appeared to elicit no response. Approximately 15 minutes after the addition of the odour the migration rate was back to normal; however, in some cases a compensatory increase was noticed. Whenever a solution produced an alarm reaction, an additional half-hour period was allowed to elapse before commencing another odour test.

The features of the repulsion were well demonstrated by a human skin odour "acclimation" test. When the hand rinse was added to the stream continuously the initial observation was an immediate drop in the number of fish from a mean rate of 40 in 15 minutes to 3 in the same time interval. The second 15-minute count was normal and the third was slightly above normal. After 45 minutes the solution was stopped and the run built up to 79 fish per 15 minutes —almost double the mean rate. The alarm reaction occurred immediately after addition of the odour. A total of 11 fish moved one step downstream, and 2 or 3 of these continued back two or more steps during the 45 minutes of continuous odour addition. No fish moved back after cessation of the odour.

None of the odours produced an increased migration rate. Both quantitative and qualitative observations showed either that an odour was not perceived or that if perceived no apparent response resulted. Sample graphs (Figure 3) show a comparison of two days' experiments. The upper graph illustrates the results of one day's tests in which no significant changes occurred, whereas the lower graph shows data from a day in which four odours each produced a significant change. Repetitions, when made, substantiated both significant and non-significant results.

Quantitative data from tests using salmon ova and testes indicated that both of these substances might be repellent. However, the tests were done early in

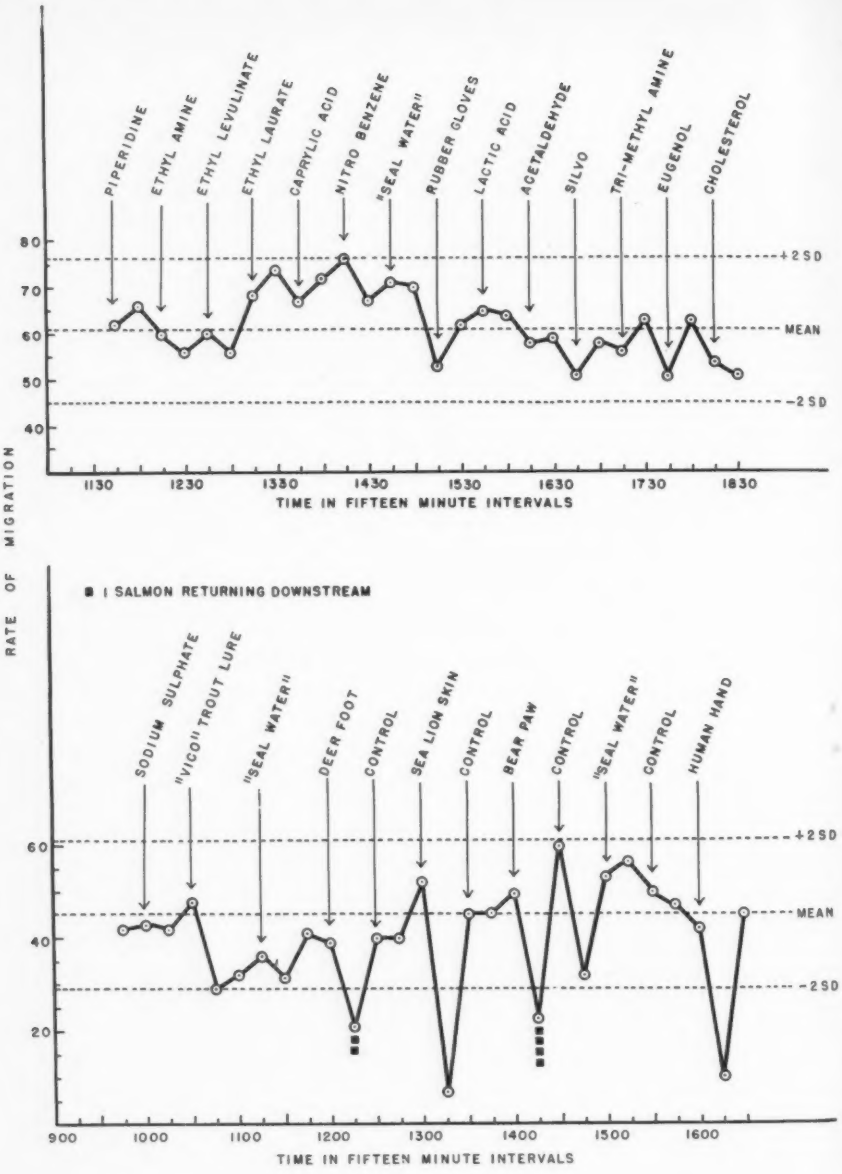

FIGURE 3. Two sample graphs taken from records on a day (*upper*) when no significant changes followed the release of a test solution, and a day (*lower*) when significant changes occurred.

the run when the migration rate was low. This fact, coupled with the fact that the material used was collected from fish of another stream, makes positive conclusions unwarranted here.

By identifying particular salmon through the presence of a distinctive scar, it was possible to follow their individual ascent up the ladder. In addition, the early morning burst of migration at daybreak could be traced as a "front" moving up the ladder. A level difference of approximately two feet separates each of the 12 pools. At certain water levels some difficulty was experienced in making the first step. From this lower pool, in which the fish tended to stay longer, they moved at a mean rate of 6 minutes per step (range 4 to 8), completing the whole ascent in an average time of 1½ hours (13 steps) for a flow of 28 cu. ft. per sec. There appeared to be a brief period of reconnoitring in each pool before the salmon would make an effort to ascend the next step. Disturbances tended to make the fish gather at the bottom of the pools; only very infrequently were they observed to return downstream, except following the introduction of some strongly deterrent odour.

DISCUSSION

The results of these experiments establish the fact that the salmon has a very acute sense of smell. The one-litre mammalian skin dilution added to 28 cu. ft. per sec. of water at a rate of 3 ml. per sec. would result in a dilution of approximately 4 parts per million. When it is considered that only a minute quantity of some unknown substance must "dissolve" in a litre during a one-minute soaking and that this is of sufficient concentration to cause a response from the top to the bottom of the ladder, it may confidently be stated that the salmon can detect a dilution of one of these mammalian skin odours at a concentration of one part in many million.

It is significant that of all the odours tested only those associated with mammalian skin caused marked response. Many of the odours released are not normally present in fresh water, whereas odours from other fish, some bruised and bleeding from misdirected jumps below the falls, and odours from numerous aquatic invertebrates and plants, must be logically ruled out as *deterrents* to upstream migration. With the exception of bacterial disease and fungus infection which are not likely at temperatures of 61° to 63°F. for uninjured fish, predators remain the major biotic threat to survival and successful spawning. Bears, sealions and seals are well known for their habit of feeding on salmon. An ability to detect potential predation at some distance by a distinctive odour, and to be alert for danger, must be of distinct survival value.

In the remaining cases it cannot be said that the odours were not perceived, since perception does not necessarily imply an observable response. However, the lack of an observable response demonstrates that these substances would have little value for repelling or attracting migrating salmon from one area of a stream to another. It is possible that the methods used were not adequate to determine whether a substance could attract salmon. The fact that the fish were moving persistently upstream indicates that they were already making a positive response to one or more environmental stimuli. An additional attractive substance might

not create an increase in the rate of migration. Under other circumstances, possibly where salmon are not utilizing a potential spawning area, a more valid test might be made.

Doudoroff and Katz (1950) have drawn attention to the frequently expressed erroneous assumption that fish can detect and avoid harmful conditions. Despite the fact that the pulp-mill effluent was used at a concentration over a million times greater than that of the mammalian skin substance, it did not deter migration. In this particular instance the salmon apparently moved readily through the area of discharge and were not impeded by the effluent. On the other hand, if these experimental conditions were not sufficient to act as a deterrent, it can be warned that the migrating salmon might follow into more polluted waters with a possibility of serious effects.

Additional observations showed that by use of hand odours individual cohoes could be displaced downstream from small side pools and that large groups of cohoes ascending a tributary could be routed downstream and back into the main river. Similar observations were recorded for the pink salmon (*O. gorbuscha*) at Puntledge River, Vancouver Island. It seems quite possible that mammalian skins, or a particular repellent substance extracted from their skin, could be used for directing salmon away from dangerous water flows.

ACKNOWLEDGMENTS

We are indebted to the Fisheries Officers of the Alberni district for their ready co-operation while the experiments were being conducted. The Alberni Pulp Mill of MacMillan and Bloedel gave free access to their grounds for obtaining samples of the effluent.

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Three Kinds of Whale-Lice (Cyamidae: Amphipoda) from the Pacific Coast of Canada, including a New Species[1]

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ABSTRACT

Three species of "whale-lice" (Cyamidae: Amphipoda) are recorded from whales caught in Canadian Pacific seas: *Cyamus scammoni* Dall, 1872, from *Rhachianectes glaucus*; *Cyamus catodontis* n. sp., from *Physeter catodon*; and *Paracyamus boopis* (Lütken, 1870), from *Megaptera nodosa*. *Cyamus catodontis* is described and illustrated.

The family Cyamidae comprises the only true parasitic group of Amphipoda. All its members, consisting of four genera and fifteen species, are ecto-parasites of Cetacea. Up to the present time, three genera and eight species have been reported from the North Pacific, of which two gerena and five species have been noted on whales in North American Pacific waters. Only one species has heretofore been recorded from whales inhabiting Canadian Pacific seas. Dall (1872a, 1872b, 1874), Cornwall (1928) and Scheffer (1939) are responsible for the North American records. In Asiatic North Pacific waters Brandt (1871, 1872), Andrews (1914), Ishii (1915), Iwasa (1934) and Hiro (1938) described or reported several species. Lütken (1873, 1887) reviewed the family Cyamidae, including the species known from the North Pacific at that time. Several species were reduced to synonyms of earlier known Atlantic species.

Three species of two genera of Cyamidae are here reported from whales caught off the British Columbia coast and landed at Coal Harbour, B.C. One species is described as new. The specimens were collected by Mr. G. C. Pike, to whom I am grateful for the privilege of examining them.

Class C R U S T A C E A
Order AMPHIPODA Latreille, 1816
Family CYAMIDAE White, 1847
Genus **Cyamus** Latreille, 1796

Cyamus scammoni Dall, 1872

This "whale-louse" was found clinging to the barnacle *Cryptolepas rachianecti* taken from a California grey whale, *Rhachianectes glaucus*. The collection consists of 2 males, 2 females and 25 juveniles.

Dall (1872a) described *C. scammoni* from the grey whale caught off California. Scammon (1874) republished Dall's description and illustrated the parasite, but both Dall's description and Scammon's illustration were inadequate. Lütken (1887) redescribed and figured, in greater detail, this species from

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specimens obtained from Dall. Andrews (1914) again reported this cyamid as being numerous on the grey whale taken in Korean seas.

The outstanding feature of this species is the coiled nature of the double branchiae.

Cyamus scammoni has not been reported from any other whale species and appears to be limited by the distribution of its host, to the North Pacific. The only localities from which it has been reported are California, Korea and the present record in British Columbia waters.

Cyamus catodontis n. sp.
(Plate I, figs. A-D; Plate II, figs. E-H)

Three males and five females of this new species of *Cyamus* were obtained from a sperm whale landed at Coal Harbour, British Columbia, on June 25, 1952.

DESCRIPTION. Males up to 7.2 mm. long by 2.8 mm. wide and females up to 5.9 mm. long by 2.4 mm. wide. Peraeon segments in general outline ovate, slightly more so in female than male. Head distinctly notched where it is fused with 1st peraeon segment, the length (including peraeon segment 1) about twice the width and ¼ the length of the entire body. Sides of head more or less parallel but with a slight lateral swelling just anterior to junction with 1st peraeon segment.

Peraeon segments 2-6, laterally elongated, segment 4 being the widest. Segment 7 subtriangular, with 2 posterolateral notches. Anteroposterior length of segments 3 and 4 less than other segments. Segment 1 rounded laterally. Segments 2, 3 and 4 in male and segments 2 and 3 in female with posterolateral angles produced; most pronounced on segment 4 of male. On ventral surface of each of segments 5, 6 and 7 of female, a lateral pair of pointed tubercles that decrease in size proceeding from segments 5 to 7; segment 5 also bears a pair of inwardly directed processes (genital valves) near middle of ventral surface. In male, anterolaterally placed, 1 pair pointed tubercles on ventral surface of segments 6 and 7; also 1 pair large tubercles posteriorly located near midline of segment 7.

First to 3rd joints of first antennae subequal (decreasing in length from 1st to 3rd joints), segment 2 approximately ½ length of head (including 1st peraeon segment); terminal joint less than ½ length of 3rd joint. Second, 3rd and 4th joints with few bristles anteriorly; 4th joint also with 3 groups of lateral bristles. Antennae-2 less than ½ length of 1st joint of antennae-1. First joint of antennae-2 slightly greater in width than length, about ½ as long as 2nd joint; 3rd as long as 2nd joint; 4th joint slightly shorter than 1st. Few bristles anterolaterally on 2nd joint and laterally as well as anterolaterally on 3rd and 4th joints.

Mouth parts are similar to those of other species of *Cyamus*. Right mandible with one incisor process bearing 2 rows of 3 teeth; a row of spines exists below the incisor process. Left mandible with 2 incisor processes each provided with 3 teeth; below the incisor process is a row of spines. Maxillae-1 with 1 lobe bearing

several comb-like teeth; palp provided with about 10 long bristles. Maxillae-2 consist of 2 lobes, the inner lobes of left and right being fused, each lobe supplied with a long bristle anteriorly; the outer lobes shorter but broader than the inner lobes, bear a group of about 7 bristles. Maxilliped, 2-segmented, inner lobe larger than outer, both bearing a few bristles; palp well developed, 4-segmented; first 3 segments subequal, terminal joint somewhat shorter; terminal and subterminal joints with few bristles.

Gnathopod-1, 6-jointed, long, slender, propodus longer than wide, bearing a rounded tooth on palm near distal end; propodus in female narrower than that in male. Gnathopod-2, 5-jointed, much larger than gnathopod-1; palm of propodus with 2 rounded teeth, anterior one more prominent than posterior; in male, teeth are larger than in female. Dactyls of both gnathopods larger in male than female.

Branchiae, about as long as peraeon segments 2–7, inclusive, in male and somewhat shorter in female, single on peraeon segments 3 and 4, provided with a short peduncle. Accessory gills in the male short (slightly longer than the peduncle of gills), bicornic, with brances of equal length. In female, accessory gills biramous, anterior rami modified into oostegites, posterior rami smaller, leaf-shaped. Oostegites oval-shaped on segment 3 and triangular on segment 4, inner margins provided with hairs or bristles.

Peraeopods 5–7 large, very similar, 5-jointed, with strongly recurved dactyl. Basal joint sharply pointed anteriorly and bearing a ventral tubercle (larger in female than in male) at the anterodistal corner. Third joint (carpus) with anterodistal end pointed, tooth on distal margin, proximal margin notched, anterior and posterior proximal ends rounded. Propodus about twice as long as wide, palm without teeth.

Pleon simple in female; in male slightly notched posteriorly and provided ventrally with membranous appendage divided into 2 rounded lobes with ciliated margins.

The holotype specimen, a female, and the allotype, a male, are to be deposited in the National Museum, Ottawa, Canada. Paratypes are in the collection of the Pacific Biological Station. The type host is the sperm whale, *Physeter catodon*. The type locality cannot be definitely stated but the whale was caught in the seas in the vicinity of the northern part of Vancouver Island, British Columbia.

Cyamus catodontis can be distinguished from each of the seven valid species of *Cyamus* almost entirely by the form and size of the branchiae or the accessory branchial appendages.

Cyamus scammoni Dall, 1872, possesses double and coiled gills, whereas in *C. ovalis* R. de Vauzème, 1834, the gills are double and sausage-shaped. The gills in *C. monodontis* Lütken, 1873, are single, sausage-shaped, about ½ the length of peraeon segments 2–7. The accessory gills in the male of this species and in *C. ceti* (Linné, 1754) are bicornic, with the posterior branch about twice the length of the anterior branch. In addition to these characters, both species are larger than *C. catodontis*; in *C. ceti* the males attain a length of 16 mm. and the females a length of 11 mm., and in *C. monodontis* the males are 11 mm. long

and the females 8 mm. long. The spines on the ventral surface of segments 5–7 are more numerous in *C. ceti* and *C. monodontis* than in the new species. In *C. balaenopterae* Barnard, 1931, the accessory gills in the male are single, whereas they are entirely lacking in the males of *C. elongatus* Hiro, 1938. The gills of these two species are considerably shorter than the length of peraeon segments 2–7. In *C. kessleri* Brandt, 1872, the anterior branch of the accessory gills in the male is somewhat shorter than the posterior branch, but more striking differences from *C. catodontis* lie in the shape of the peraeon segments and the proximity

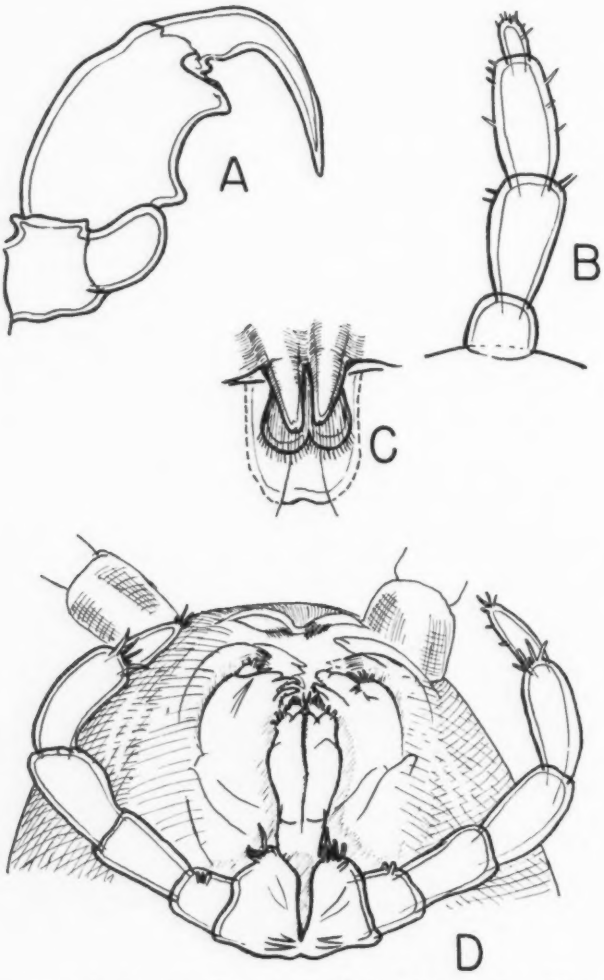

PLATE I. *Cyamus catodontis*, n. sp. (Drawn by D. Denbigh.) A: Gnathopod-2, male. B: Antennae-2, male. C: Pleon, male, ventral view. D: Mouth parts, male.

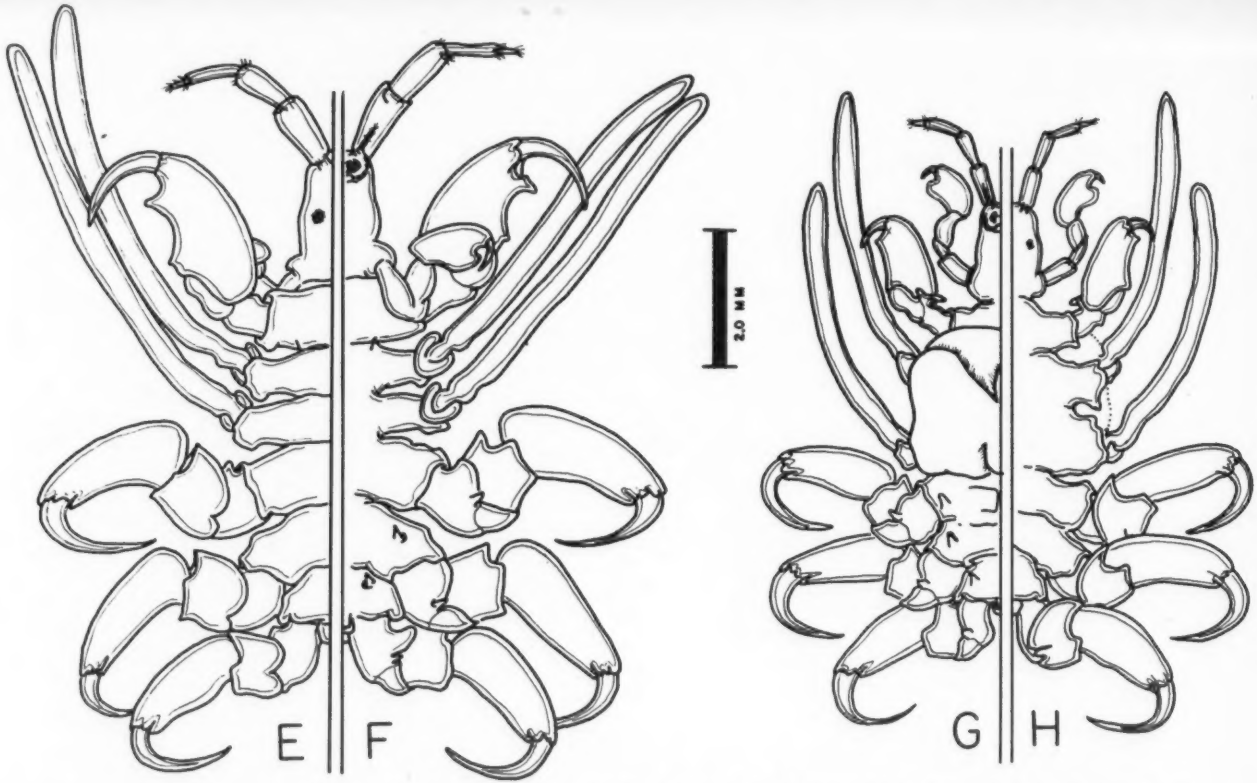

PLATE II. *Cyamus catodontis* n. sp., flattened to show details of appendages. (Drawn by D. Denbigh.) E: Male, left half, dorsal view. F: Male, left half, ventral view. G: Female, right half, dorsal view. H: Female, right half, ventral view.

of the segments laterally. *Cyamus kessleri* also possesses a horizontal tubercle, directed laterally, at each of the lateral margins of segments 3 and 4 in the male and no tubercles on segments 5–7 of the male. In contrast to these seven species, *C. catodontis* possesses, on each of segments 3 and 4, a single, sausage-shaped pair of gills of length about equal to the length of peraeon segments 2–7, inclusive. The accessory gills in the male are short, biramous, with the branches of equal length. The horizontal tubercles on segments 3 and 4 of the male, characteristic of *C. kessleri*, are absent. A pair of tubercles are present ventrally on each of segments 6 and 7 in the male, in addition to the very large pair posteriorly on segment 7 that is apparently present in all cyamids. *Cyamus catodontis* is one of the smallest species of whale-lice.

Other species of cyamids that have been placed in the genus *Cyamus* at one time or another, but are now regarded as belonging to other genera, are *Paracyamus boopis* (Lütken, 1870), *Paracyamus erraticus* (R. de Vauzème, 1834), *Paracyamus nodosus* (Lütken, 1860), *Paracyamus gracilis* (R. de Vauzème, 1834), *Paracyamus physeteris* (Pouchet, 1888), *Platycyamus thompsoni* (Gosse, 1855) and *Isocyamus delphini* (Guérin-Méneville, 1836).

Cyamus catodontis is the third species of cyamid to be recorded from the sperm whale, but the first true species of *Cyamus*. *Paracyamus physeteris* (Pouchet, 1888) Stephenson, 1942 (=*Cyamus physeteris* Pouchet, 1888, and *Cyamus fascicularis* Verril, 1902) was described from the Azores (Pouchet, 1888, 1892) and the Bermudas (Verril, 1902). *Paracyamus boopis* (Lütken, 1870) Sars, 1895, was recorded by Barnard (1932) from a sperm whale taken off South Africa.

Genus **Paracyamus** Sars, 1895
Paracyamus boopis (Lütken, 1870) Sars, 1895

Synonyms: *Cyamus suffusus* Dall, 1872; *Cyamus boopis* Lütken, 1870.

The collection of *P. boopis* contains numerous specimens of males, females (most of which are carrying embryos) and juveniles taken from the humpback whale, *Megaptera nodosa*, which is the common host of this cyamid. Cornwall (1928) and Scheffer (1939) recorded its presence on this host in British Columbia and Alaska, respectively. Dall (1872a, 1872b) described it as *C. suffusus* n. sp., from the humpback whale of the California coast. Lütken (1887) reexamined Dall's specimens and considered *C. suffusus* almost certainly identical with *C. boopis*, a view upheld by later workers. Sars (1895) introduced the new genus *Paracyamus* for Lütken's *C. boopis*, distinguishing this new genus from the older *Cyamus* on the basis of absence of maxillary palps in the adults of *Paracyamus*.

Complete descriptions with figures of *P. boopis* have been published by Lütken (1873), Sars (1895) and Barnard (1932).

Paracyamus boopis is a universal parasite of the humpback whale. A record of its presence on the sperm whale has already been mentioned.

In Japanese seas *Cyamus elongatus* Hiro, 1938, has been described, the host being cited as *probably* the humpback whale.

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Notes on the Life-History of the Polychaete *Dodecaceria fewkesi* (nom. n.)[1]

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ABSTRACT

Dodecaceria fewkesi (Fewkes) is a new name for the cirratulid polychaete formerly known as *D. pacifica*. It builds colonies of calcareous tubes on rock faces in suitable localities on the east and west coasts of Vancouver Island between tide-marks. A sexual reproduction by autotomy followed by regeneration is common and colonies seem to result from a single individual by a repeated operation of this process. Individuals in a given colony are invariably of one sex. Fertile eggs could not be obtained either by mixing ripe oocytes and sperms or by adding sperms to water containing female colonies. They did result from keeping male and female colonies together, provided the colonies had been recently removed from their natural habitat. The early stages of development are described and figured.

INTRODUCTION

The genus *Dodecaceria* is a member of the family Cirratulidae (Polychaeta) distinguished from other genera mainly by the possession of a pair of heavy tentacular cirri and a limited number of pairs of branchiae, all on anterior segments. It was set up by Oersted (1843) for the species *D. concharum*. This species is of wide distribution, and representatives are usually found in galleries drilled into shells or *Lithoamnion* or other calcareous structures. It was exhaustively studied by Caullery and Mesnil (1898) who described its occurrence in three forms, one always sedentary and two others in which epitokes also are known. One of the latter (form B) has since been made into a new species, *D. caulleryi*, by Dehorne (1933). It is distinguished from *D. concharum* by several minor morphological characters, but chiefly by the possession of a unique method of asexual reproduction described under the name "schizometamery". In this process a portion of the median region of the body separates into individual segments each of which produces two buds which, having attained the form of small adults, separate. The segment repeats this process once and then it withers. All four buds eventually become adult animals and the anterior and posterior ends of the original animal regenerate a new head and tail respectively.

There is only one record of *D. concharum* from the Canadian Pacific coast (E. and C. Berkeley, 1948), but another species of the genus hitherto known as *D. pacifica* (Fewkes), occurs in quantity on both the east and west coasts of Vancouver Island (E. Berkeley, 1929; E. and C. Berkeley, 1932). This species was originally described from California by Fewkes (1889) under the name *Sabella pacifica*. Hartman (1944) pointed out that this name is preoccupied necessitating a new specific designation as well as the generic reclassification

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made by Moore (1909) .We are accordingly substituting the name "*fewkesi*" for "*pacifica*".

Moore (1909, 1923) described the species fully and we have only the following modifications to make in this description. The pygidium, in extension, ends in a ring of four or more lobes surrounding the anus. The capillaries in the median region of the body are not always entirely displaced by spines. The extent of replacement is a very variable character, every degree occurring in different individuals. Finally, in respect of coloration, we find a great deal more variation than Moore's descriptions suggest (*vide infra*). It is noteworthy in this connection that no epitokes, such as are described in *D. concharum* (form C) and *D. caulleryi*, have been observed in *D. fewkesi*.

Until recently the localities in which *D. fewkesi* was known to occur off the Canadian Pacific coast were difficult to reach, but in 1952 a good collecting area was found near Dodd's Narrows, readily accessible by road from Nanaimo, and this made the present study possible. It was undertaken primarily to see if anything comparable to the curious method of reproduction described by Dehorne for *D. caulleryi* could be found in *D. fewkesi*. This we have not succeeded in finding in spite of a year-round series of observations. Nevertheless, the possibility of its occurrence is not entirely excluded, since we have not been able to procure material from its natural habitat during the autumn and winter months when sufficiently low tides occur only at night. We have been obliged to rely upon aquarium-held material during those months, and there is reason to think that the animals do not behave altogether normally in captivity (see section on Fertilization of Eggs). During the observations, however, some other points of interest in connection with the species have been noted and these form the subject of the present paper.

COLONIAL HABIT

D. fewkesi constructs and lives in calcareous tubes built in masses on rock faces which are usually more or less vertical, but this is not invariably the case. The tubes are fused together on a common base from which the upper ends project freely for a distance of anything up to approximately half an inch. The anterior portion of the tubes and their mouths are roughly circular and 1 to 3 mm. in diameter, but often two or three adjacent tubes are fused, making irregular terminations (Figure 1). The tube masses vary considerably in shape and size and usually occur in distinct colonial formations, but fusion of adjacent masses frequently takes place and a rock face may be more or less completely covered. They are found only in fairly rapidly moving, well aerated, water and only in the intertidal area, from the lowest to about mid-tide mark. When covered with water, the worms extend the first few body-segments and spread their branchiae and tentacular cirri, which are kept in constant motion, but they withdraw into their tubes at the fall of the tide or if disturbed. They can also double on themselves in their tubes and extrude their anal ends through the openings. This seems to be the normal method of excretion. Not infrequently more than one individual extrudes both head and tail from the mouth of a single tube. The

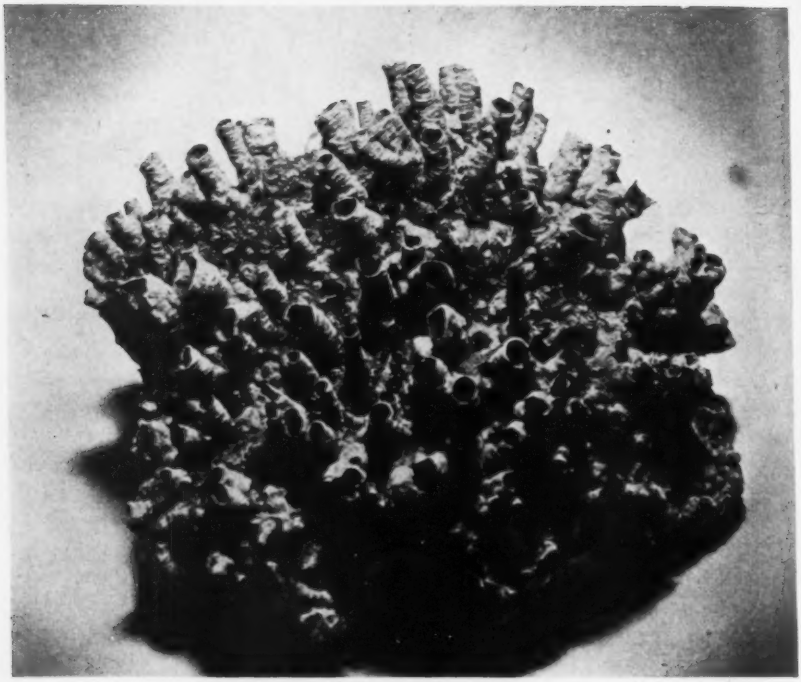


FIGURE 1. Typical colony of *Dodecaceria fewkesi*, dried.

tubes usually stand approximately vertically to the rock face supporting the colony or to any projection there may be on it, but, on cutting into a colony, it is found that, although the main tubes tend to run parallel down to the base, this is by no means uniformly the case. There are many smaller tubes running at various angles to the main tubes, presumably outgrowths from them, so that it is impossible to cut off a portion of the colony without destroying at least a few of the inmates.

PIGMENTATION AND REGENERATION

The body-colour of full-grown specimens of *D. fewkesi* is normally very dark brown or almost black, excepting the branchiae and tentacular cirri which are often a rather light yellow-brown and appear red by transmitted light owing to circulating blood. A very strikingly coloured extract is obtained from the worms when they are placed in fresh water or alcohol. Whilst cold the extract has a bright yellow-green fluorescence. When the aqueous solution is heated, it assumes a deep blue colour. The pigment is extracted by ether from the aqueous solution. It produces dark stains on the skin when the worms are handled, and also stains other organisms associated with them in the colonies. From the readiness with which the colouring matter is extracted it would seem to be a constituent of the integument and may readily account for the development of

its dark colour. Similar pigments are described from *Dodecaceria concharum* by Caullery and Mesnil (1898) and from *Arenicola marina* by Fauvel (1927). Investigation of its chemical nature would be a matter of considerable interest.

When a colony of *D. fewkesi* is cut into the worms which are found are by no means uniform either in size or in colour. Many are small and many are more yellow than black, the dark pigmentation being only slightly, or not at all, developed over at least part of the body areas, but the most striking variation from the normal black colour is the occurrence of bright yellow terminal regions, either anterior or posterior, or, rarely, both, in many individuals otherwise dark in colour. Frequently the black portion of the body consists of only a few median segments. The yellow terminal portions of the body are often much more slender than the rest so that there is an abrupt transition, not only in colour, but also in width and, in the case of a yellow anterior region, the branchiae and tentacular cirri are often only partially developed. Quite obviously these are cases of regeneration, and every condition of adjustment of body-width from the most slender to the full width of the rest of the body (in which case nothing but the colour indicates regeneration) can be found. The development of the dark pigmentation of the regenerated portions appears to take place quite slowly.

The frequency of these cases of regeneration is far too great to be attributed to recovery from accidental injury, such as is known to occur in many Polychaeta. Injury of this sort would probably be very rare in the sheltered conditions within the colony and it seems almost certain that these cases indicate that autotomy followed by regeneration is a normal process of reproduction in the species and that colonies are developed by repetition of the process. This probability is supported by the facts that living fragments of the worms, both anterior and posterior, are frequently found in the tubes and (as will be shown later) that the inhabitants of individual colonies are invariably of one sex.

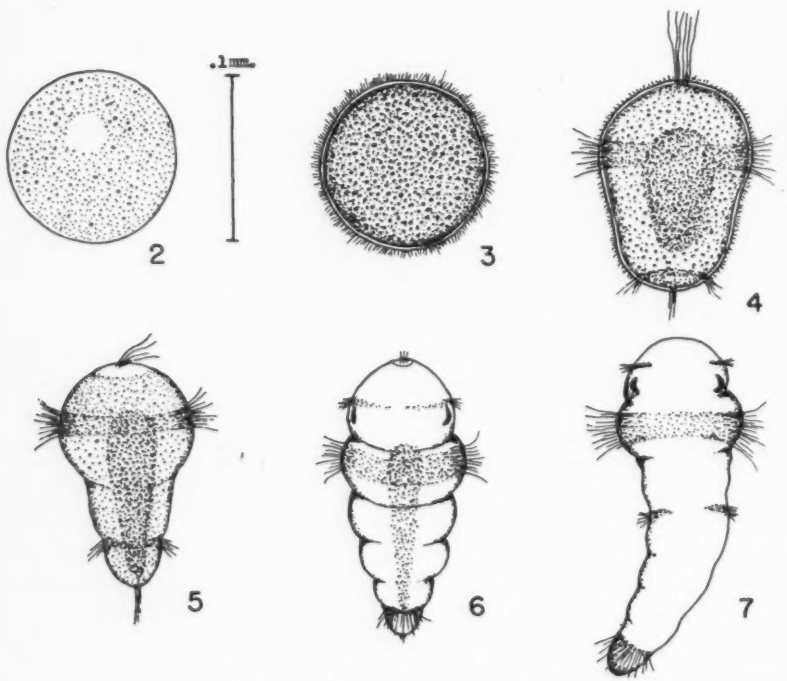
An interesting case of regeneration, not only of an anterior and a posterior region, but also of an abnormal side branch, in a fragment of *Dodecaceria concharum*, is recorded by Caullery and Mesnil (1897). This case is particularly pertinent to the present observations since they mention that, whilst the original fragment had the usual dark colour, the regenerated portions were yellow. We have observed a similar abnormal development of a side branch in a single instance in *D. fewkesi*. In the same paper, Caullery and Mesnil refer to other cases of abnormal regeneration in a number of families of Polychaeta. Wilson (1937) records one in a species of *Eulalia*, and we encountered a very striking instance in a specimen of *Eurythoe paupera* (Grube) some 20 cm. long, some years ago, which had developed a second posterior region as long as the original one from halfway down its length. However, all these are records of abnormal occurrences.

Normal regeneration of lost or injured regions or parts occurs commonly in many families of Polychaeta including Cirratulidae, but the occurrence of autotomy precedent to regeneration as a process of reproduction has been suggested in only a few species and, excluding the very specialized process of schizometamery in *Dodecaceria caulleryi*, only in the aberrant genus *Ctenodrilus* amongst Cirratulidae.

SEXUAL ACTIVITY

Colonies were first collected in late July and August, 1952. All were obtained in close proximity to one another and at low tide level. It was found that they could be easily removed from the supporting rock by gently working round the base with chisel and hammer until loosened, but a few worms were inevitably lost and some injured. The colonies were transferred to, and kept in, a tank with running sea water. In a few hours some of the worms, including many of those injured during removal, were discharged from each colony. Water in which injured specimens were being examined microscopically was frequently found to contain oocytes, and some uninjured worms from the tank, on being teased out, ejected similar oocytes. Isolated oocytes are a pale pink colour, but in mass they have an orange tint. They appear to be spherical or only slightly flattened. The largest and, presumably, the ripest ones are about 0.1 mm. in diameter and contain a germinal vesicle about 0.025 mm. in diameter and fine, opaque, granular cytoplasm (Figure 2).

A systematic examination of the colonies was made to ascertain how generally these sexually mature females occurred. A piece was cut off each colony,



FIGURES 2–7. Developmental stages of *Dodecaceria fewkesi*. **2**: Fertilized egg. **3**: Ciliated stage (18 hours). **4**: Trochopohore larva (24 hours). **5**: 48-hour larva. **6**: 72-hour larva. **7**: 100-hour larva.

the worms extracted, and a sample of them examined by teasing out. Extraction was greatly facilitated by adding a few drops of sea water saturated with phenol to the dish containing the piece of colony; after a few hours many of the worms had emerged and the remainder were readily extracted without injury. In a number of the colonies no single individual with ripe gametes was found. In others a large fraction of those examined contained them. Some individuals were distended with oocytes of uniformly large size and seemed to contain little else. In others they were relatively few and of various sizes, indicating immaturity. Oocytes were rarely found in cases in which considerable regeneration had recently taken place and never in the regenerated portions.

Discovery of these sexually mature females led to a search for corresponding males. This was at first unsuccessful, but eventually an individual was found, in the tank containing the colonies, from which, on pricking, we obtained a mass of sperm and, finally, this individual was associated with a single colony from which two more ripe males were obtained. In the remainder of the sample from this colony the gonads were quite undeveloped. Subsequent examination showed that the sexually mature individuals in any one colony were invariably of one sex. No single instance of a colony with individuals of both sexes has been encountered. This is in accordance with the view already expressed that autotomy followed by regeneration is responsible for the development of the colonies. It would be anticipated in this event that all the members of the colony would retain the sex of the originator.

Out of 11 colonies collected in the late summer of 1952 three were female, the samples drawn from them showing respectively 42, 50 and 83 per cent individuals with developed oocytes, and one was male showing about 7 per cent sexually mature. The remaining individuals in these, and all in the other seven colonies examined, showed no sexual products, but it was impossible to determine by the method employed whether this was due to their being immature or mature and spent.

In 1953 collecting of colonies was started at the first daylight low tides, which occurred in April. They were all taken from the same series of rock faces at Dodd's Narrows as those examined in 1952, except in one instance, in May, when two colonies were taken from a rock at a higher tide level. The following table (in which the term "neutral" is used to signify colonies which contain no individuals with recognizably developed gonads) summarizes the results:

Date	*Colonies examined*	*Male colonies*	*Female colonies*	*Neutral colonies*
April 5	8	3	0	5
May 17	3	1	1	1
June 27	7	2	4	1
July 25	11	3	4	4
Aug. 7	14	0	9	5
Aug. 24	13	1	6	6

No sufficiently low tides for collecting occurred in daylight after August. The relatively greater frequency of female colonies, except in the spring, when male

colonies seem to predominate, suggests that this is the period of active sexual reproduction and that the males are largely spent later in the season. However, many females seem to carry more or less mature oocytes throughout the year.

FERTILIZATION OF EGGS

Female individual worms may be fairly easily recognized without injuring the specimens when sexual maturity has reached so advanced a stage that the body-cavity appears to be almost entirely filled with oocytes. At this stage they can be seen through the body-wall and are readily expelled when the animal is pricked in the median region. Similar recognition of male individuals is more difficult. Males from which sperm is readly expelled when they are pricked are usually of a lighter colour in the median region than in the rest of the body owing to distension, but this is not invariably the case and distension may occur in the absence of sperms.

Following the recognition of the separation of the sexes in colonies, attempts were made to effect fertilization of what appeared to be ripe oocytes. No success was obtained by mixing the oocytes with sperms extracted from apparently ripe males. No eggs were laid by ripe females extracted from their tubes nor from colonies containing ripe females, whether active sperms from a ripe male were added or not, though the worms remained alive and active for weeks in these conditions. We found the same thing to be the case when colonies containing ripe females and ripe males, respectively, were placed together in an aquarium, if the colonies had previously been kept in captivity for some days. Eventually, however, this last method proved successful, but only if the colonies were introduced into the aquarium within a few hours of their removal from their natural habitat. For some reason yet to be explained, captivity, if at all prolonged, seems to arrest breeding even though the inhabitants of the colonies appear to be perfectly healthy and a number of them fully sexually mature. By using colonies as speedily after collecting as the sexes could be determined, fertilized eggs have been obtained on two occasions. However, the necessity for speed was not realized until June and the successful experiments were carried out in that month and in July, probably well after the peak of the breeding season was past. It is likely that success would be more uniform earlier in the year. It is hoped to test this point next year and, at the same time, attempt to throw some light on the arrest of breeding activity in colonies removed for some time from their natural habitat.

In early August no colony containing ripe males was obtained. Later in the month the single male colony that was found was put into an aquarium with three colonies containing females whose oocytes appeared fully mature within a few hours of collecting them, but, although they were kept together for several days, no eggs were laid.

DEVELOPMENT OF EGGS

In both the June and the July experiments single, recently collected colonies of each sex were put together in an aquarium. Twenty-four hours later small patches of pink eggs were found on the bottom of the aquarium around the

female colony. How many hours previously they had been laid is not known. The eggs were already fertilized, but whether fertilization had taken place in the water or in the tube previous to laying could not be determined. Evidence of fertilization was afforded by the facts that, as compared with the oocyte, the integument was thickened and the contents somewhat contracted from it, the germinal vesicle was no longer clearly discernible, and the cytoplasm was denser and more coarsely granular. In some cases, too, the onset of cleavage was evident. This could be followed until a fairly advanced stage (possibly the 32-cell stage) was reached, after which the cytoplasm became too dense. In a few cases the surface of the egg was uniformly ciliated (Figure 3) and slowly revolving.

Caullery and Mesnil found that the atokous form (Form A) of *Dodecaceria concharum* reproduced parthenogenetically, the eggs developing within the female to a fairly advanced larval stage. It is not probable that the early development observed in the eggs laid by *D. fewkesi* was similarly induced, but the possibility cannot be totally excluded since no emission of sperms from the male colonies was observed. However, the fact that eggs from colonies containing ripe females were produced only in the presence of male colonies suggests very forcibly that sperms played a part. Certainly there is no viviparity in *D. fewkesi* involving sustained retention of the larvae within the female such as is said to occur in *D. concharum.*

Some of the eggs laid by *D. fewkesi* were transferred from the aquarium into other vessels immediately they were found. Eighteen hours later most of them were distinctly ciliated all over and revolving freely (Figure 3). Six hours later many of them had assumed the form shown for the 24-hour trochophore of the allied form *Audouinia tentaculata* by Wilson (1936), except that in some cases neither the telotroch nor the posterior cilia could be made out and in some the uniform short ciliation of the body surface shown in the earlier stage was still present as well as the characteristic bands of long cilia (Figure 4). At this stage the larvae remained on or near the bottom of the containing vessel, but, on being disturbed, swam rapidly, revolving meanwhile. The later stages of development, so far as they have been followed, agree generally in form and size with those of *Audouinia tentaculata* as described and figured by Wilson. Figure 5 shows the stage reached 48 hours after the eggs were found; all trace of the earlier short ciliation of the body-surface had disappeared at this stage. Figure 6 shows the stage after 72 hours, at which stage mere traces of apical cilia remained and two eyes were well defined. Figure 7 shows the stage reached after 100 hours. In these later stages the larvae were swimming freely. In the last they were very contractile and segmentation could not be clearly traced. The development has not yet been followed beyond the stage shown in Figure 7. It should be noted that the periods ascribed to the stages of development are measured from the time at which the eggs were first found. Several hours should probably be added to arrive at their actual ages measured from fertilization.

OTHER POLYCHAETA ASSOCIATED WITH *D. FEWKESI*

The following three species of polychaeta are constantly found living in the colonies of *D. fewkesi*: *Lumbrinereis inflata* Moore, *Nainereis laevigata* (Grube),

and *Syllis elongata* (Johnson). Of these the first is the most conspicuous. It appears to occupy any vacant tube it may find in a colony and also to establish itself among the tubes. A number may be present in quite small colonies. It attains much larger size in this association than it is known to reach when free-living. Specimens have been found up to 100 mm. long and 4 mm. wide, whereas the largest previously recorded is 70 mm. long and 2 mm. wide. It is very easily observed in the colony by reason of both its size and brilliant irridescence. *Nainereis laevigata* is almost as common and is conspicuous because of its bright yellow colour, but it is not unusually large. *Syllis elongata* is one of several syllids found on the colonies, but it is by far the most common. It is usually among the tubes rather than within any one of them. Several individuals will often be found in a single colony.

Colonies are frequently found surrounding anemones or other sessile organisms, and a species of rock-boring clam is almost invariably present at the base of them, its siphons penetrating between the tubes to the surface.

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The Rockfish *Sebastodes rubrivinctus* in British Columbia Waters[1]

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ABSTRACT

The "Spanish flag" or "flag snapper" (*Sebastodes rubrivinctus*) is of common occurrence in the long-line catches from deep water adjacent to the British Columbia coast, but has not previously received formal recognition. It is recognizable by the four wide, bright red vertical bands on the sides of the body, the background being white or pale pink. About 100,000 pounds were landed by Canadian fishermen in 1952.

To date, no official recognition has been given to the existence of the "Spanish flag", *Sebastodes rubrivinctus* Jordan and Gilbert, in waters adjacent to the British Columbia coast, despite the fact that it is of considerable abundance and market importance. This species of rockfish was described in 1880 by Jordan and Gilbert as *Sebastichthys rubrivinctus* and three years later was placed in the genus *Sebastodes*. It was recorded then as a rarity, inhabiting deep water off the southern California coast. The species was redescribed by Thompson (1915) as *Sebastodes babcocki* from a specimen obtained off the Alaska coast, apparently on the basis of a difference in peritoneum coloration (Alverson and Welander, 1952). Although Thompson entitled his article "A new species of the genus *Sebastodes* from British Columbia . . . " he gave no information on the location of capture in that region. Presumably for this reason, the species did not qualify for recognition by Clemens and Wilby (1946) in their description of the fishes of the Pacific coast of Canada.

In a live or freshly killed condition *S. rubrivinctus* is readily distinguishable from all other members of the genus by the presence on the body of four wide, bright red bands on a white or pale pink background (Figure 1). A fifth band, lighter and much less distinct than the rest, progresses downward and backward from the eye. The only other rockfish inhabiting British Columbia waters that has vertical bars on the side of the body is *S. nigrocinctus*, the banded rockfish. In that species, however, the bands are jet black and generally less in width than the diameter of the eye. *S. nigrocinctus* is also distinguished by the presence of a very narrow interorbital space and prominent cranial ridges.

In a preserved state *S. rubrivinctus* is less easy to identify, since the red stripes fade rapidly, leaving a uniform light coloration to the whole body. According to the key of Alverson and Welander (1952), the species may be distinguished by the presence of a silvery peritoneum, absence of a supraocular spine, presence of cycloid scales on the head and a multifid posterior lacrymal spine. According to the key of Clemens and Wilby (1946) the following set of features would distinguish the species from all other rockfishes in British Colum-

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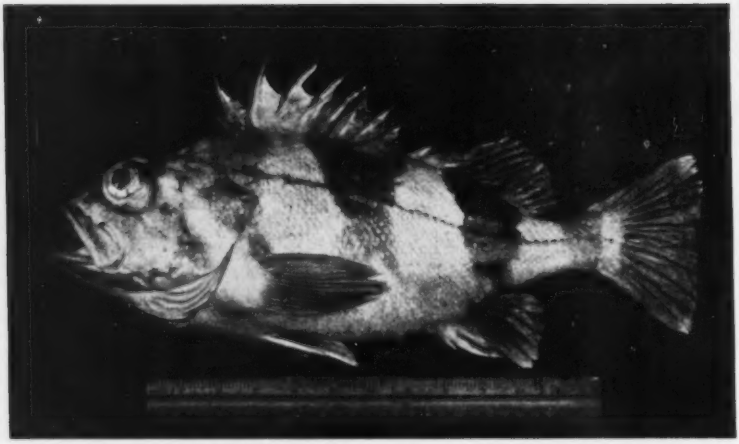

FIGURE 1. The Spanish flag, *Sebastodes rubrivinctus* (Jordan and Gilbert). This specimen was captured in Dixon Entrance, British Columbia at a depth of 100 fathoms and approximately 19 miles N. by E. of Rose Spit on Graham Island.

bia waters: a flat interorbital space, more than 41 but usually less than 47 pores on the lateral line, and a multifid posterior lacrymal spine.

The following detailed description of *Sebastodes rubrivinctus* follows the pattern initiated by Clemens and Wilby and is based on 10 specimens obtained from Dixon Entrance, off the north coast of the Queen Charlotte Islands:

SPANISH FLAG *Sebastodes rubrivinctus* Jordan and Gilbert, 1880.

Body elongate, moderately deep, depth 2.4 to 2.7 in standard length. Head with upper profile moderately steep, straight to slightly concave; mouth terminal, moderate; lower jaw slightly projecting; symphyseal knob very small; interorbital space flat, medium width; cranial ridges moderately developed; cranial spines: nasal, prefrontal (preocular) frontals II and III (postocular and tympanic), parietal, moderately developed, sharp; supracleithral cleithral, strong and sharp; opercular, narrow, sharp; preopercular, upper three narrow, sharp; lower two short, stout; lacrymal lobes, 2, spines on posterior lobe, multifid or sometimes bifid (2 to 4), minute; rakers on first gill arch 8 to 10 + 20 or 21, short, moderately robust. Fins: dorsal (1), XIII, 13 to 15, deeply notched, membranes of spinous portion deeply incised, longest spine about 2.7 into length of head; anal III, 6 or 7, second spine longer and stronger than the third; pelvic I, 5, thoracic, not reaching the anus; pectoral, 19, not reaching the anus. Scales: mostly cycloid on head, ctenoid in other regions, in oblique rows above the lateral line, 40 to 57. Pores: on lateral line, 42 to 48. Colour: light pink or white with four broad, bright red cross-bars extending as low as level of the mid-pectoral base. First, between the third dorsal spine and the occiput, extending across the operculum to the origin of the pectoral fin; second, beginning broadly between the fifth and eleventh dorsal spine, narrowing ventrally to the level of the mid-pectoral rays; third, beginning in the anterior half of the soft-rayed dorsal,

extending ventrally on the anal fin; fourth, on the caudal peduncle, beginning broadly and narrowing ventrally. Indistinct red band extending posteroventrally from the eye across the preoperculum and operculum. Pectoral and caudal fins bright red. Peritoneum silvery or dusky, but according to Alverson and Welander (1952) there is considerable variation: silvery (52 per cent), silvery with black blotches (19.7 per cent), dusky or pepper effect (15.8 per cent) and black (12.5 per cent).

Length to 25 inches.

The Spanish flag has been captured on several occasions in operations of the research trawler *Investigator No. 1*, of the Pacific Biological Station. Three specimens were obtained by the writer on July 26, 1947, approximately 10 miles SSW. of Rafael Point off the west coast of Vancouver Island, in 52 fathoms. Fourteen specimens were obtained on July 18, 1953, 19 miles N. by E. of Rose Spit in Dixon Entrance at depths of 80 and 100 fathoms. One specimen was obtained on August 22, 1953, by W. E. Barraclough, nine miles west of Freeman's Pass in Hecate Strait at a depth of 50 fathoms.

From the record of landings by otter-trawlers and long-liners, the Spanish flag appears to be a deep water species, occurring most commonly at depths over 100 fathoms. Because most Canadian otter-trawlers fish no deeper than 50 or 60 fathoms, the species does not form a significant part of the catch by that type of gear. In contrast, it is estimated that over half of the rockfish landed by long-line vessels is of this species. Apparently, catches are greatest in depths between 100 and 200 fathoms and rarely occur at depths greater than 250 fathoms.

The species is common in all open coastal regions of British Columbia. The greater part of the commercial catch is taken off the northwestern coast of Vancouver Island, off the edge of the Goose Island bank in Queen Charlotte Sound, and off the west coast of the Queen Charlotte Islands northward to Cape Ommaney in Alaska. No records have been obtained in deep water surveys in Georgia Strait. The Canadian catch in 1952 is estimated to have been approximately 100,000 pounds, taken almost entirely by long-line vessels.

According to Thompson (1915), there was no market for the Spanish flag or other rockfish species in the early days, and great quantities were destroyed during the course of the halibut and blackcod fishery. Like most of the deep water fishes, this species is usually dead from the effects of decompression, by the time is is brought to the surface. When landed on deck, the belly is distended with air; the eyes are greatly protruded and pockets of air may be observed along the base of the dorsal and other fins.

The name "Spanish flag" is nowhere in use by Canadian fishermen. It is usually called "red cod" or "canary". The name "flag snapper" is apparently in common use by United States fishermen.

Range: Southern California to southeastern Alaska.

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